UNIVERSIDAD COMPLUTENSE DE MADRID
FACULTAD DE FARMACIA
DEPARTAMENTO DE ANATOMÍA Y ANATOMÍA PATOLÓGICA COMPARADA (ANATOMÍA Y EMBRIOLOGÍA)

TESIS DOCTORAL

Variaciones anatómicas del sistema vascular sanguíneo en medicina veterinaria:

arteria ilíaca interna del perro

MEMORIA PARA OPTAR AL GRADO DE DOCTOR

PRESENTADA POR

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Variaciones anatómicas del sistema vascular sanguíneo en medicina veterinaria. Arteria ilíaca interna del perro

Trabajo presentado para aspirar al Grado de Doctor por la UCM

Luis Javier Avedillo Cea

Madrid, abril de 2015

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INFORMAN:

que el trabajo titulado "Variaciones anatómicas del sistema vascular sanguíneo en medicina veterinaria. Arteria ilíaca interna del perro", presentado por Luis Javier Avedillo Cea como memoria de tesis para aspirar al grado de Doctor por la Universidad Complutense de Madrid, ha sido realizado bajo nuestra dirección,

que el mencionado trabajo se considera idóneo para ser presentado en la modalidad de "formato de publicaciones" de acuerdo con la normativa vigente, Real Decreto 99/2011 de 28 de enero (BOE 10.02.2011) y Acuerdo del Consejo de Gobierno de la UCM de 6 de noviembre de 2012 (BOUC 21.12.2012),

Revisado el manuscrito damos el visto bueno para que se proceda a la lectura y defensa del mismo.

Madrid, abril de 2015

Fdo. Ignacio Salazar   Fdo. Nieves Martín

AGRADECIMIENTOS

Este trabajo está dedicado a la memoria del profesor de Anatomía y Embriología Veterinaria ***Joaquín Camón Urgel*** *que murió el 10 de marzo de 2009. Descanse en paz.*

Ver materializada la conclusión de este estudio que comenzamos en el año 1997 con la disección de los primeros animales, supone una inevitable sensación de plenitud que te lleva a concentrar la mayor parte del mérito en el aporte que has hecho al conocimiento anatómico. Sin embargo, el análisis objetivo te muestra inmediatamente que la magnitud de este aporte hubiese sido del todo imposible sin la participación de personas que han facilitado las cosas para que este trabajo llegue a término. Por ello, es para mí un verdadero placer utilizar este espacio para ser justo y consecuente con ellas, expresándoles mi más sincero agradecimiento.

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Agradezco enormemente el apoyo recibido por parte de mi familia y especialmente agradecer todo lo que mis padres han hecho por mí. Gracias a ellos soy la persona que soy y gracias a ellos he aprendido a que hay que luchar para conseguir las cosas.

Finalmente, y no por ello menos importante, quiero agradecer a Tamara Alonso Pantoja el estar junto a mí.

RESUMEN

Las variaciones anatómicas del sistema vascular sanguíneo, concretamente del sistema arterial, correspondientes a la arteria ilíaca interna del perro adulto han sido estudiadas morfológicamente de acuerdo con el procedimiento habitual seguido en técnica anatómica, disección y microdisección, y con la consiguiente repleción de los vasos con látex coloreado. Cuando ha sido menester, se ha realizado el correspondiente análisis microscópico para lo cual se ha acudido a la técnica histológica convencional. Ante la imposibilidad de agrupar exhaustivamente los 116 perros utilizados (machos y hembras) por razas, debido a que muchos de ellos eran mestizos, se ha optado por hacer una clasificación en cuanto al perfil de su cabeza en braquicéfalos, mesaticéfalos y dolicocéfalos; otra clasificación ha sido establecida por tamaño de acuerdo con el peso aproximado de los animales: pequeño (menor de 6 kg), mediano (entre 7 y 20 kg) y grande (más de 20 kg). Los datos obtenidos de las 232 muestras se han tratado de acuerdo con el test chi-cuadrado y los resultados se han considerado estadísticamente significativos cuando $p \leq 0.05$.

Por cuestiones estratégicas y en aras de una mayor claridad las tres ramas de la arteria ilíaca interna –arteria glútea caudal, arteria pudenda interna y arteria umbilical– se han estudiado independientemente unas de otras. Tanto para la arteria glútea como para la pudenda se han encontrado considerables variaciones anatómicas predominantemente relativas al origen de cada una de ellas y el de sus ramas. Tales variaciones se han asociado con los factores de sexo, lado (derecho/izquierdo), perfil y tamaño y se han hecho propuestas de clasificación de las diferentes modificaciones encontradas. En comparación con las arterias anteriores, las variaciones anatómicas de la arteria umbilical son lógicamente menores ya que la función vascular de esta arteria es previa al nacimiento. Sin embargo, una interesante variación de la misma afecta a su permeabilidad, entendiendo en este caso por permeabilidad la capacidad de la citada arteria de continuar como arteria propia después del nacimiento, circunstancia que el perro se supone que se pierde; ese aspecto ha sido desde luego tratado. Finalmente y dado que una variación llamativa del estudio está relacionada con la organización arterial del conjunto perineal se ha considerado pertinente resaltar ese aspecto.

SUMMARY

The anatomical variations of the blood vascular system, specifically of the arterial tree, corresponding to the internal iliac artery of the adult dog have been morphologically studied in consonance with the standard procedures currently used in anatomical technique, dissection and micro dissection, with the corresponding repletion of vessels with colored latex. When necessary, a microscopical analysis has been done, following the conventional histological technique. Due to the impossibility to group exhaustively the 116 used dogs (males and females) by breed, many of them being mongrels, a classification was set based on the profile of their heads. This led to dividing them into three categories: brachycephalic, mesaticephalic and dolichocephalic dogs. They were also classified by weight: small (6kg or less), medium (between 7 and 20kg weight) and big (over 20kg). The collected data from the 232 specimens was analysed and the chi-squared test for independence or homogeneity was used to analyse differences in sex, side (symmetry), profile and size, and the results were considered statistically significant when $p \leq 0.05$.

For strategic reasons and with the goal of being as clear as possible, the three branches of the internal iliac artery –gluteal caudal artery, internal pudendal artery and umbilical artery– have been studied independently. In both the gluteal and pudendal vessels, significant anatomical variations were found, related majorly to their own origin and the origin of their branches. Such modifications have been related to sex, side, profile and size, and several proposals have been done to classify the mentioned variations. In comparison to what happens with these two arteries, the anatomical variations of the umbilical artery are obviously less important, mainly because its vascular function is restricted to the period previous to birth. Nevertheless, an interesting variation of the umbilical artery concerns its permeability, that is to say the capacity of the artery to continue carrying out blood to the bladder, which in dogs is supposed to be lost; that issue has also been studied. Finally, it was found relevant to point out a striking variation of the study partly devoted to the arterial organization of the perineal vessels taken as a whole.

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1. INTRODUCCIÓN

El boletín oficial del estado número 35, de fecha 10 de febrero de 2011, publicó el decreto 99/2011 por el que se regulan en la actualidad las enseñanzas oficiales de doctorado. Textualmente en tal decreto se anota que "*tiene por objeto regular la organización de los estudios de doctorado correspondientes al tercer ciclo de las enseñanzas universitarias oficiales conducentes a la obtención del Título de Doctor o Doctora, que tendrá carácter oficial y validez en todo el territorio nacional*". En el mencionado decreto se establece que el desarrollo final y específico de la normativa que regula los estudios de doctorado es competencia exclusiva de las universidades. En ese sentido se indica que las universidades establecerán requisitos y criterios propios según lo previsto en sus estatutos, en la normativa de la Comunidad Autónoma correspondiente y, desde luego, en el decreto 99/2011.

De acuerdo con lo anterior, el Consejo de Gobierno de la Universidad Complutense de Madrid (UCM), en su sesión del 6 de noviembre de 2012, aprobó la Normativa de desarrollo del Real Decreto 99/2011 que regula los estudios de doctorado, tal y como aparece publicado en el BOUC número 14, de fecha 21 de diciembre de 2012. En el artículo 10.3 de la citada disposición se establece que: "*Se podrán presentar Tesis Doctorales en "formato publicaciones". En las publicaciones que compongan la Tesis el doctorando deberá haber participado como autor principal y se habrán editado en revistas de la especialidad recogidas en índices de calidad contrastados o de similar nivel científico en libros. El director y tutor del doctorando certificarán el carácter de la aportación del doctorando en las publicaciones aportadas. La recopilación de publicaciones deberá siempre acompañarse de una introducción en español, si las publicaciones están en idioma distinto, que incluya una revisión del estado actual del tema, los objetivos y/o hipótesis, una discusión integradora y las conclusiones".* Por otra parte los diferentes programas de doctorado de la UCM especifican el número de artículos de investigación, publicados o con aceptación definitiva para su publicación, realizados durante el período de tutela académica del doctorando que son necesarios para que puedan considerare en la modalidad de referencia; en el caso particular de que se trata son dos.

Al cumplirse los requisitos aludidos esta tesis doctoral se presenta en la modalidad de "formato de publicaciones", y se aportan dos trabajos publicados en los años 2014 y 2015; asimismo se incluyen dos manuscritos adicionales en proceso de revisión, que son continuación de las dos aportaciones ya publicadas. En cualquier caso, lógicamente la temática de la presente memoria se ajustará a lo establecido, tal y como se recoge sumariamente en el índice incluido en páginas anteriores. No obstante, se entiende que las publicaciones que se aportan son suficientemente demostrativas del trabajo realizado, ya que –como es preceptivo en revistas del Journal Citation Reports (JCR)– en cada una de ellas en los apartados de introducción, material y métodos, resultados, discusión y referencias bibliográficas, se determina con detalle el estudio llevado a cabo. Mi actividad como alumno de tercer ciclo en la Facultad de Veterinaria de Madrid se ha desarrollado en dos etapas; en la primera de ellas del curso académico 2004-05 al 2007-08 y la segunda, más reciente, del curso 2011-12 al 2014-15.

1.1. Variaciones anatómicas. Consideraciones generales

Genéricamente consideradas las variaciones anatómicas (VAs) constituyen un tema apasionante para los morfólogos por múltiples motivos pero probablemente los tres que se comentan a continuación son más relevantes que otros: i) porque las VAs se establecen en relación y/o comparación con la organización y constitución anatómica típica para un modelo previamente establecido, ii) porque las VAs no representan ningún tipo de disfunción y por lo tanto no guardan relación directa con las malformaciones congénitas, y iii) porque su conocimiento es de gran interés fundamentalmente a la hora de realizar determinadas actuaciones médicas. En los siguientes epígrafes se incidirá en cada uno de esos aspectos pero conviene, en este primer apartado de la introducción, orientar sobre el particular.

En cierta medida habría que admitir que los “modelos previamente establecidos” con los cuales hacer comparaciones es algo utópico ya que modelos anatómicos rigurosos no existen para el conjunto de las especies, ni para las especies pertenecientes exclusivamente a la *Clase Mammalia*, ni tan siquiera para aquellos mamíferos considerados de mayor interés, por la sencilla razón de que la VARIABILIDAD MORFOLÓGICA es una constante en el mundo animal (Darwin, 1988). No obstante, igualmente cierto que lo anterior es el hecho de que para progresar en el conocimiento –en este caso particular de la ciencia anatómica– es aconsejable, sino imprescindible, disponer de patrones o modelos como punto de partida y sobre ellos introducir todas las matizaciones que sean procedentes. Esa ha sido sin duda la tónica universal para elaborar los tratados de la especialidad.

Con respecto al segundo punto es fundamental tener en cuenta que en la realización del trabajo que ha dado lugar a la elaboración de esta memoria se ha seguido la pauta más comúnmente aceptada de que las VAs no llevan aparejada ningún tipo de disfunción orgánica, ni tampoco que su presentación sea consecuencia de cualquier tipo de patología (Lippert & Pabst, 1985). Se entiende que las VAs responden a la variabilidad, rasgo que puede estar más o menos influenciado por factores tales como la edad, el sexo, la raza y otras circunstancias (ver más adelante). Aunque es evidente que, de la misma manera que ciertas patologías provocan la aparición de VAs, las malformaciones congénitas inciden en cambios morfológicos del sujeto afectado, unas y otras –variaciones y malformaciones– encierran conceptos bien distintos entre sí (Marden et al., 1964; Stevenson & Hall, 1993). Incidir sobre esa diferenciación conceptual está fuera de los objetivos que se pretenden en esta introducción, si bien no está de más aclarar que etimológicamente las malformaciones congénitas representan el todo o una parte del individuo que se engendró de forma defectuosa, con lo cual las malformaciones congénitas podrían entenderse como una modalidad de anomalía del desarrollo o, expresado de otra manera, como fallos del sistema en formación. Tales fallos pueden ser debidos a causas externas (ambientales) o internas (hereditarias), en un alto porcentaje pasan desapercibidos como sucede con las reabsorciones y abortos, o no se manifiestan nunca externamente durante la vida del individuo como ocurre en procesos cognitivos, por lo que habitualmente las malformaciones congénitas se asocian a defectos morfológicos manifiestos que pueden afectar a una sola estructura (malformaciones únicas o asiladas) o a varias estructuras (malformaciones múltiples o asociadas).

Por último, en relación con el tercer punto citado, a pesar de la obviedad de la trascendencia que muchas veces tienen las VAs y de las diferentes llamadas de atención que se han hecho para incidir en ellas (ver por ejemplo: Educational Affairs Committee, American Association of Clinical Anatomists, 1996; Sañudo et al., 2003), interesa señalar que es prácticamente imposible recoger todas las variaciones que pueden presentarse en una determinada especie por lo cual lo más importante es saber que existen y tener presente tal circunstancia en el momento de hacer una intervención, un trasplante o una exploración clínica, y de esta manera evitar errores.

1.2. Las variaciones anatómicas del sistema vascular sanguíneo en la especie humana

Lógicamente las específicas variaciones anatómicas del sistema vascular sanguíneo (VASVS) son una variante de las VAs por lo que las cuestiones de tipo general son idénticas a las previamente comentadas y, al mismo tiempo, hay aspectos particulares para este tipo de modificaciones. Concretamente, el estudio de las VASVS ha sido una preocupación histórica en medicina humana como lo demuestran las publicaciones que sistemáticamente se dedican al tema y lo actualizan, bien a través de informaciones de casos clínicos, trabajos de investigación específicos o revisiones. En ese sentido y casi sin excepción, todas las regiones anatómicas son abordadas y en los últimos meses, con fecha posterior a la redacción de los manuscritos que se adjuntan a esta memoria, son numerosas las publicaciones que han aparecido. A manera de ejemplo y con la finalidad además de poner de manifiesto la distinta metodología empleada por los autores se recogen diversos artículos actuales referidos a diversas estructuras pertenecientes al aparato locomotor (Hou et al., 2013; Chakravarthi et al., 2014; Kusztal et al., 2014; Nasr et al., 2014; Calisir et al., 2015), a la columna vertebral y a la base del cráneo (Hashemi et al., 2013; Siddiqi et al., 2013; Ciolkowski et al., 2014; Gitkind et al., 2014; Krzyzewski et al., 2014; Pekcevik & Pekcevik, 2014; Krzyzewski et al., 2015; Pekcevik, 2015), a la cavidad torácica (Jie et al., 2014; Karakan et al., 2014; Polguj et al., 2014; Romanek et al., 2014; Jie et al., 2015; Nagashima et al., 2015) y a la cavidad abdominal (Aristotle et al., 2013; Gümüs et al., 2013; Nayak et al., 2013; Panagouli et al., 2013; Sebben et al., 2013; Luan et al., 2014; Wang et al., 2014; Buffoli et al., 2015).

El enfoque que se hace a continuación para dar una idea real de las VASVS que interesan a la arteria ilíaca interna (AII) parte de la evidencia de que todos los libros clásicos de anatomía humana incluyen con mayor o menor extensión descripciones sobre las VASVS en general y de las que están asociadas a la AII. En ese sentido han destacado autores de la escuela de anatomía francesa, entre ellos Léo Testut, quien a finales del siglo XIX publicó su excelente “Traité d'anatomie humaine” que posteriormente fue revisado por su discípulo André Latarjet, versión traducida a muchos idiomas y con gran éxito de divulgación en España (Testut & Latarjet, 1979). En esa obra los autores dedican específicamente una introducción a las VASVS, en la que se refieren a variaciones en cuanto al origen de las arterias, su tamaño, su recorrido, sus relaciones, sus ramificaciones (incluyendo posibles anastomosis) y su terminación. Consideran que determinados tipos de fenómenos hidromecánicos tienen influencia en la presentación de variaciones que, por lo general, se traducen en un exceso o defecto de convergencia de los vasos así como a una inversión en el volumen de los mismos, variaciones que en cualquier caso ya están presentes antes del nacimiento. La particular sistemática que desarrollan los autores en su obra para la descripción anatómica de los vasos de una determinada región es acorde con lo anterior puesto que, en primer lugar, describen lo que ellos entienden es la normalidad, patrón o modelo y, a continuación, incluyen un comentario de "variedades", lo cual hacen sistemáticamente para cada arteria (ver figura 1). Otros muchos ejemplos son también elocuentes para demostrar la preocupación de los anatomistas humanos en el tema de las VASVS pero los dos elegidos (Lippert & Pabst, 1985; Dubreuil-Chambardel, 1925) se estiman suficientes porque resumen adecuadamente los esquemas más habituales para representar las modalidades de variaciones arteriales (ver figuras 2 y 3).

Existen pocas dudas, sin embargo, para la mayoría de los anatomistas contemporáneos en considerar el estudio de Buntaro Adachi (Adachi, 1928) como la obra de referencia universal en cuanto a la descripción del sistema arterial de los humanos, y muy especialmente en cuanto a sus VAs. El citado anatomista japonés tuvo mucho interés en orientar el tema de las VASVS desde un punto de vista antropológico puesto que suponía que las diferencias raciales entre pueblos podrían representar un factor determinante a la hora de definir variaciones (Olry & Lellouch, 2003; Watanabe et al., 2012). Además, afortunadamente para los estudiosos de la anatomía vascular, existe un atlas que se actualiza periódicamente, que está disponible y se puede consultar sin coste en el que se recogen variaciones de los vasos (Bergman et al., 2006).

Los detalles que describe Adachi para el caso particular de la arteria hipogástrica o AII son especialmente esclarecedores (ver figura 4) y representan al mismo tiempo una actualización y comparación con un trabajo previo realizado sobre una población de individuos polacos (Jastchinski, 1891). En esa misma línea de enfoque comparativo de la arteria hipogástrica se continuaron las publicaciones, en unos casos de la población americana entre blancos y negros (Ashley & Anson, 1941), de Rumania (Fatu et al., 2006), y de la India (Naveen et al., 2011).

A pesar de lo anterior se desea insistir en el hecho de que la publicación de Adachi sigue considerándose como una especie de biblia académica para el tema en cuestión, aunque hace unos años se publicó un artículo (Yamaki et al., 1998) sobre la AII en el que se introdujeron modificaciones (ver figura 5) a la clasificación original de Adachi.

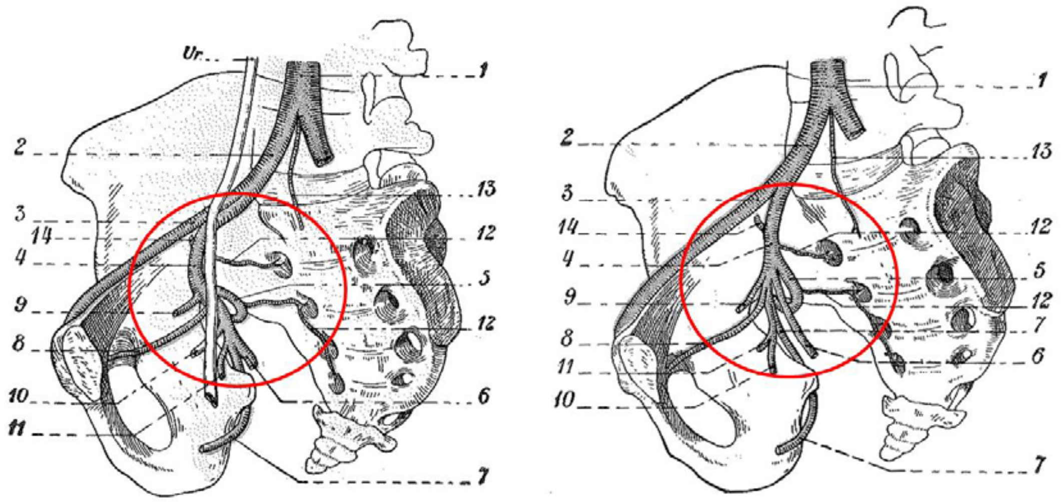

Figura 1. Reproducción de esquemas originales que ilustran lo que los autores consideran normalidad (izquierda) y variaciones (derecha). 1, aorta; 2, arteria ilíaca primitiva; 3, arteria ilíaca externa; 4, arteria ilíaca interna; 5, arteria glútea; 6, arteria isquiática; 7, arteria pudenda interna; 8, arteria obturatriz; 9, arteria umbilical; 10 y 11, arterias viscerales; 12, arterias sacras laterales; 13, arteria sacra media; 14, arteria iliolumbar; Ur, uréter; círculo rojo, enmarca las ramificaciones de la ilíaca interna. Según Testut & Latarjet, 1979.

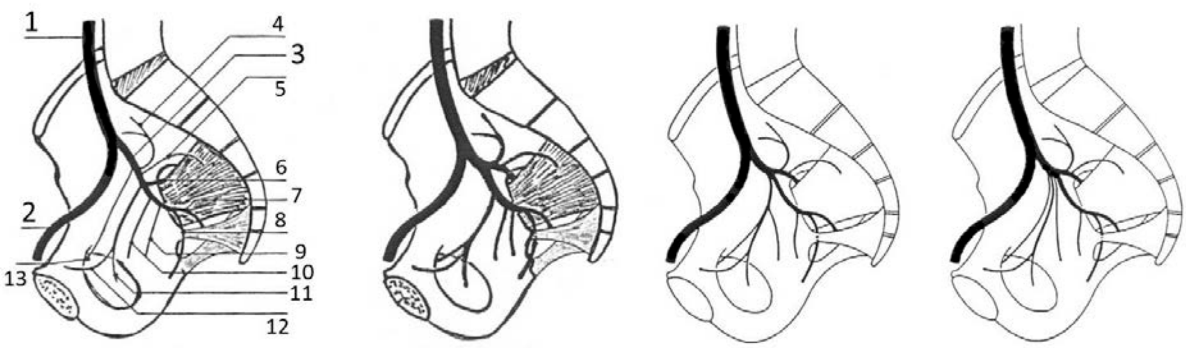

Figura 2. Reproducción de esquemas originales que ilustran lo que los autores consideran normalidad (izquierda/con numeración) y variaciones (derecha). 1, arteria ilíaca común; 2, arteria ilíaca externa; 3, arteria ilíaca interna; 4, arteria iliolumbar; 5, arteria sacra lateral; 6, arteria glútea superior; 7, arteria glútea inferior; 8, arteria pudenda interna; 9, arteria rectal media; 10, arteria uterina; 11, arteria vesical superior; 12, arteria umbilical; 13, arteria obturatriz. Según Lippert & Pabst, 1985.

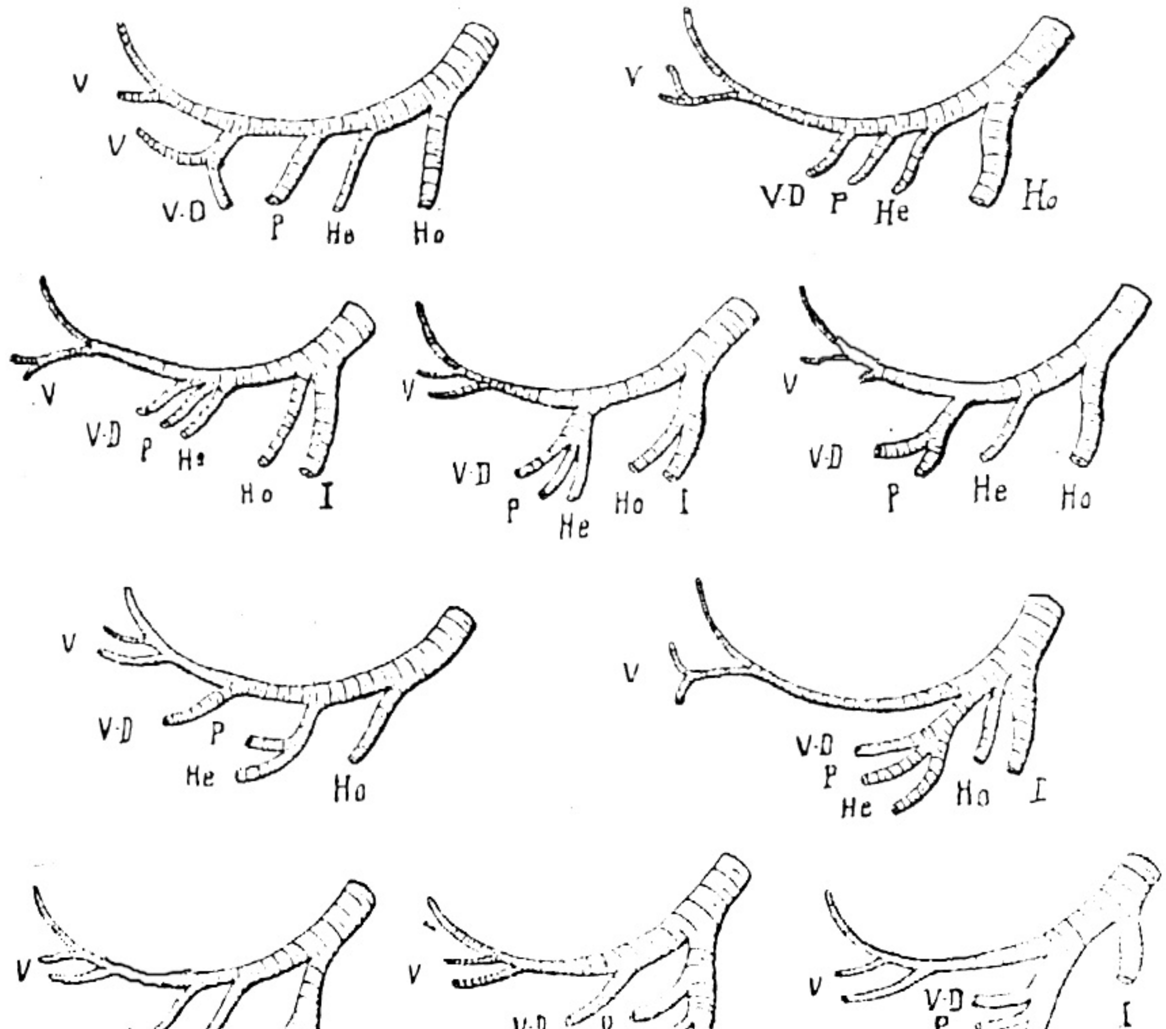

Figura 3. Reproducción de esquemas originales que ilustran las variaciones de las ramas viscerales de la arteria ilíaca interna. Según Dubreuil-Chambardel, 1925

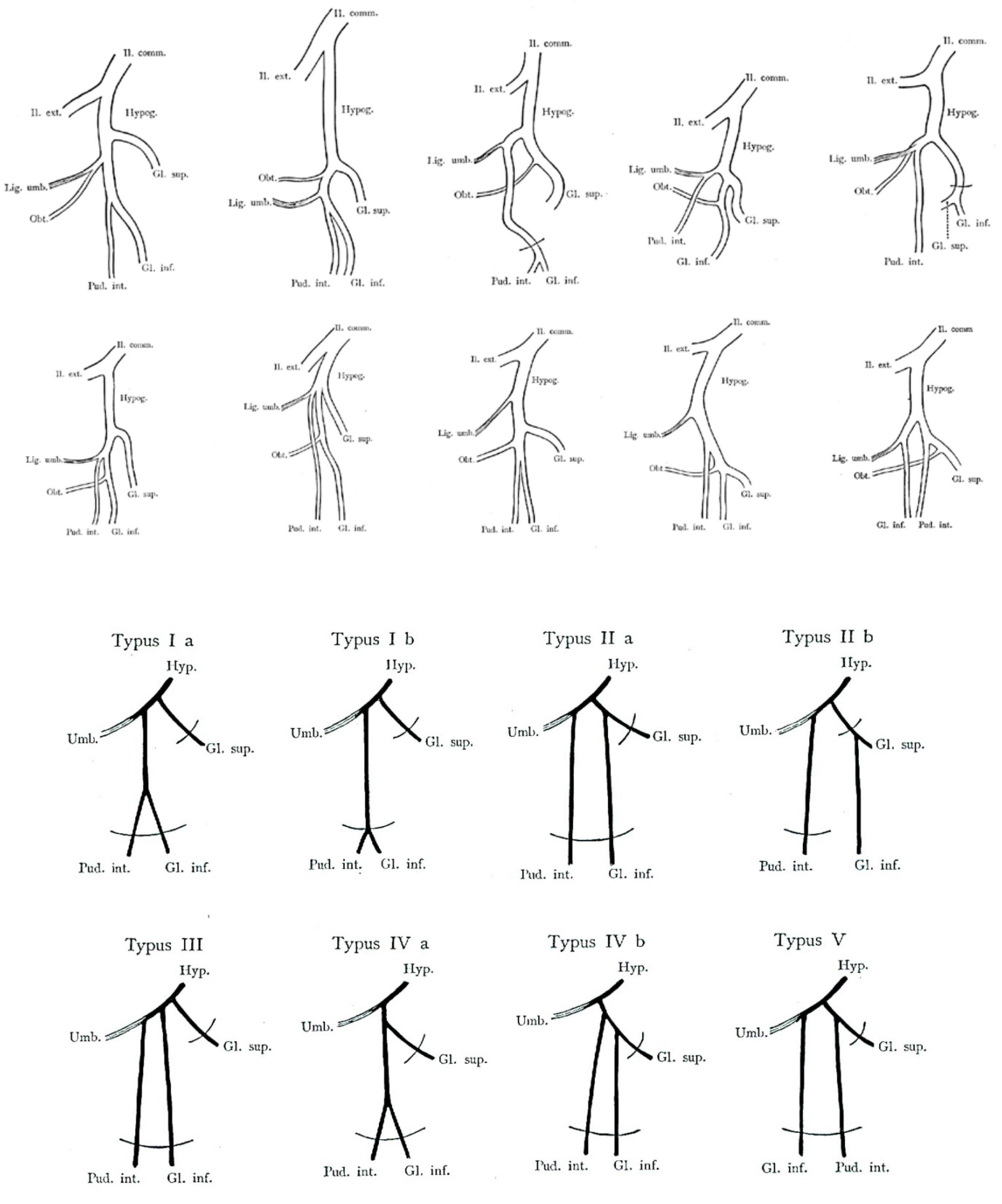

Figura 4. Reproducción de dibujos (dos filas superiores) y esquemas (dos filas inferiores) originales que resumen las variaciones más comunes de la arteria hipogástrica (ilíaca interna). Il comm, arteria ilíaca común; Il ext, arteria ilíaca externa; Hypog, arteria hipogástrica o ilíaca interna; Lig umb, ligamento umbilical; Umb, arteria umbilical; Obt, arteria obturatriz; Gl sup, arteria glútea superior; Gl inf, arteria glútea inferior; Pud int, arteria pudenda interna. Según Adachi, 1928.

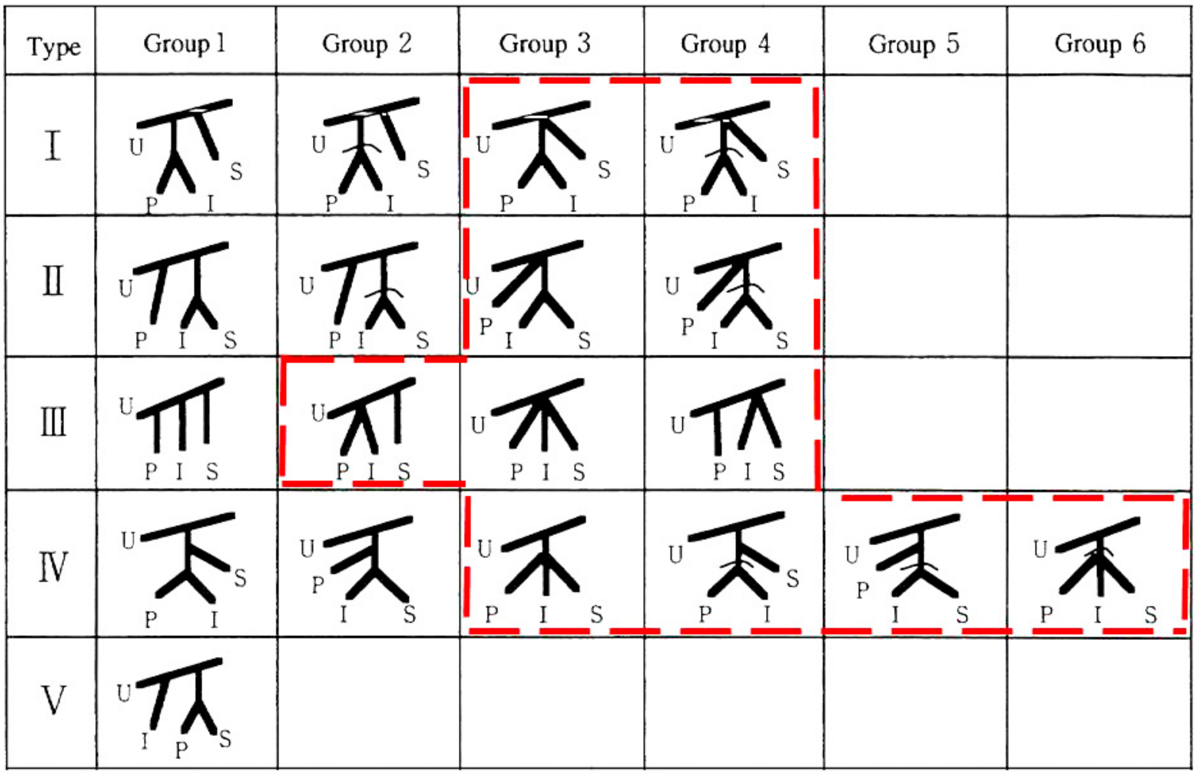

Figura 5. Reproducción del esquema original que ilustra las adaptaciones/modificaciones (enmarcado en rojo) a la clasificación original de Adachi en cuanto a las variaciones anatómicas de la arteria ilíaca interna. I, arteria glútea inferior; P, arteria pudenda interna; S, arteria glútea superior; U, arteria umbilical. Según Yamaki et al., 1998.

1.3. Las VASVS en los mamíferos domésticos

A diferencia de lo que sucede en la especie humana, en los mamíferos domésticos las VASVS es un tema muy poco y mal explorado, aunque bien es verdad que existen publicaciones aisladas que tratan de modificaciones de los vasos en los animales mencionados siguiendo distintas estrategias. En ese sentido merece la pena consignar aquellos que tratan específicamente determinado tipo de variaciones morfológicas (Mannu, 1914; Barone, 1954; Franke, 1958; Vitums, 1962; Cuthberston & Gilfillan, 1964; Kowateschev, 1968; Gomercić & Babic, 1972; Steiner et al., 1983; Zimmermann et al., 1989), así como una publicación más reciente (González et al., 2014) que incluye variaciones de la AII en el gato (ver discusión).

La escasez de información sobre el particular aconseja acudir a los datos que ofrecen los libros de texto clásicos más actuales (Getty, 1975; Schummer et al., 1981; Barone, 1996; Evans & de Lahunta, 2013) en los cuales las descripciones del sistema arterial están predominantemente orientadas a establecer diferencias entre especies. Con el mismo criterio está elaborada la *Nomina Anatómica Veterinaria* (NAV) (International Committee on Veterinary Gross Anatomical Nomenclature, 2012) y su versión ilustrada (Constantinescu and Schaller, 2011). El enfoque que incluyen esas fuentes de información facilita un teórico modelo o patrón para cada animal, que en ciertos casos abarca la organización general del sistema en machos y hembras (ver figura 6). Es necesario mencionar que, asimismo, son frecuentes las alusiones sobre modificaciones a las descripciones que de ciertos vasos realiza cada autor, pero tales menciones son por lo general ambiguas. Algo muy similar ocurre en el tratamiento particular que se da a la AII, vaso sobre el que existe una publicación específica (Nitschke & Preuss, 1971), que complementa una previa (Gyürü & Kovács, 1967), donde se establecen tres tipos diferentes para los animales perisodáctilos, artiodáctilos y carnívoros, en relación con el tipo característico predominante en la especie humana (ver figura 7).

Como quiera que para el estudio que se ha llevado a cabo, y que se presenta en esta memoria, era imprescindible disponer de un modelo lo más objetivo posible sobre la organización y distribución de la AII en el perro, se ha tenido especialmente en cuenta toda la información contenida en los libros de anatomía veterinaria, elaborados a partir de las innumerables y meticulosas disecciones de anatomistas prestigiosos, y en la NAV en sus versiones de clasificación y representación (ver figura 8).

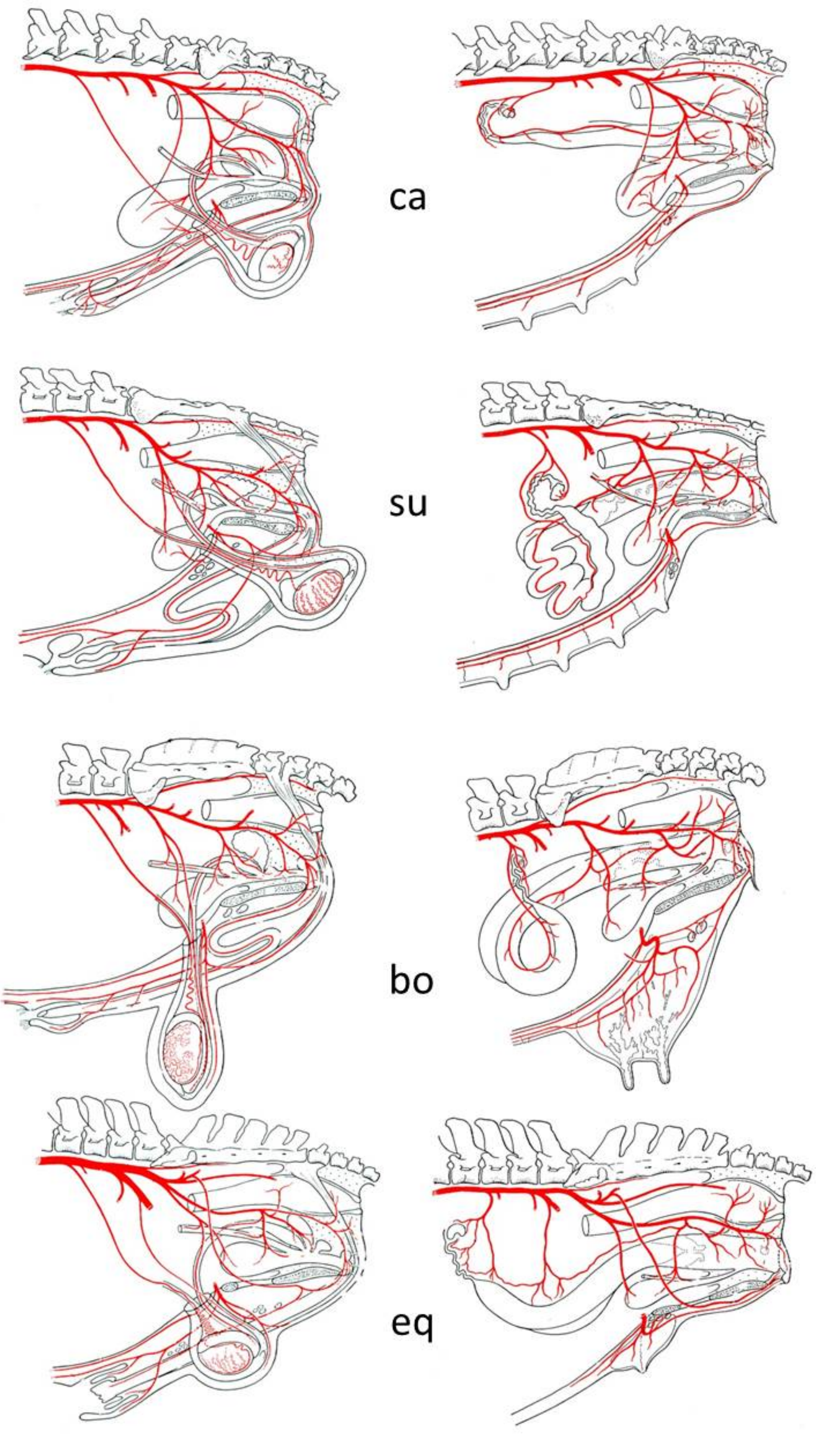

Figura 6. Reproducción de los esquemas originales que ilustran la distribución de los vasos arteriales en el conjunto de la pelvis para el perro (ca), cerdo (su), vaca (ru) y caballo (eq) en machos (izquierda) y hembras (derecha). Según Schummer et al., 1981.

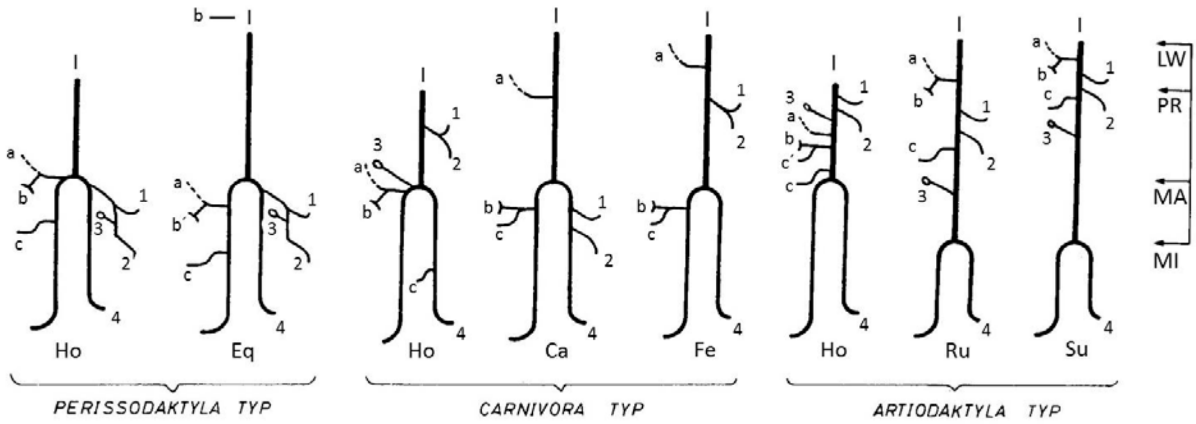

Figura 7. Reproducción del esquema original que ilustra las variaciones anatómicas de la arteria ilíaca interna en distintos modelos por especies. Ca, Canidae; Eq, Equidae; Fe, Felidae; Ho, Hominidae; Ru, Ruminantia; Su, Suidae. I, arteria ilíaca interna; 1, A. iliolumbar; 2, A. glútea craneal; 3, A. obturatoria; 4, A. glútea caudal; a, A. umbilical; b, A. uterina/conducto deferente; b´, A. del conducto deferente; c, A. vaginal/prostática; c´, A. prostática; d, A. pudenda interna. LW, última vértebra lumbar; PR, promontorio, MA, incisura isquiática mayor; MI, incisura isquiática menor. Según Nitschke & Preuss, 1971.

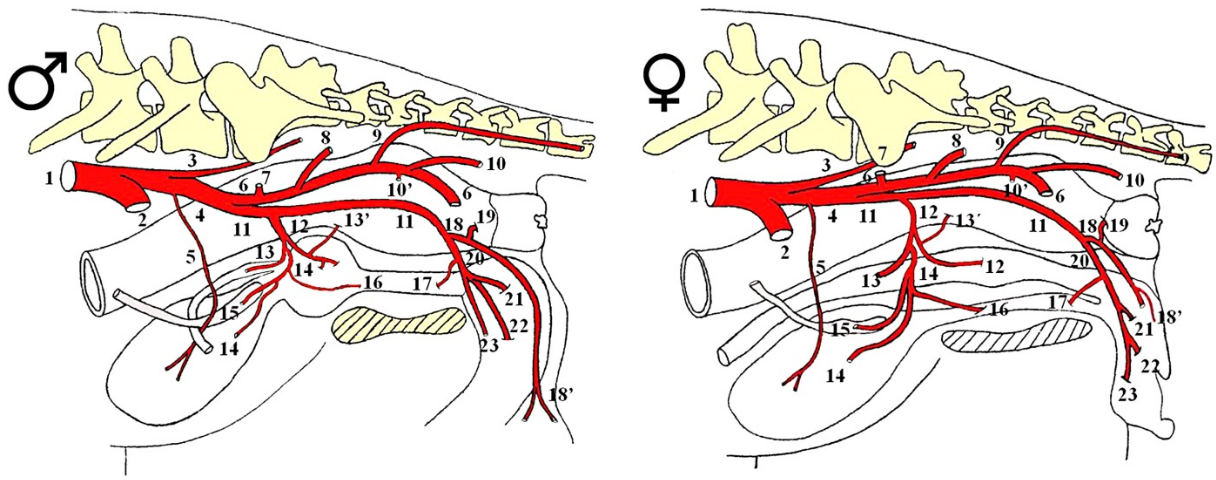

Figura 8. Reproducción del esquema original que ilustra el modelo elaborado para establecer las variaciones anatómicas de la arteria ilíaca interna en el perro. 1 aorta abdominal; 2 ilíaca externa; 3 sacra media; 4 ilíaca interna; 5 umbilical; 6 glútea caudal; 7 iliolumbar; 8 glútea craneal; 9 caudal lateral; 10 perineal dorsal; 10’ satélite del nervio isquiático; 11 pudenda interna; 12 prostática/vaginal; 13 conducto deferente/uterina; 13’ rectal media; 14 vesical caudal; 15 rama ureteral; 16 rama uretral; 17 uretral; 18 perineal ventral; 18’ rama escrotal dorsal/ labial dorsal; 19 rectal caudal; 20 pene/clítoris; 21 bulbo del pene/del bulbo del vestíbulo; 22 profunda del pene/clítoris; 23 dorsal del pene/clítoris. Según Avedillo et al., 2014.

2. OBJETIVOS

Con la resumida descripción incluida en el apartado anterior se ha pretendido exponer una idea general de lo que son y significan las variaciones anatómicas del sistema vascular sanguíneo, concretamente del sistema arterial, con una aproximación al estado actual del tema en la especie humana y en los animales mamíferos de especial interés veterinario. De esa manera se ponen las bases que conducen a establecer un planteamiento del problema, también esbozado previamente, que llevan necesariamente a definir los objetivos del estudio. De acuerdo con la información manejada durante la realización del trabajo y en la elaboración de esta memoria parece obvio que en los denominados mamíferos domésticos –pertenecientes a las especies *Equus caballus, Bos taurus, Capra hircus, Ovis aries, Sus scorfa, Canis familiaris, Felis catus*– existe un vacío importante en el tema en cuestión, en parte justificable precisamente por el número dispar de especies que se incluyen, por las diferencias raciales y, en la mayoría de los casos, por la práctica imposibilidad de llevar a cabo este tipo de estudios en número suficiente para considerarse estadísticamente fiables. Las razones de esa dificultad son elementales para el caso de los animales de abasto y para los animales de compañía los motivos son más bien de tipo ético. No obstante, es necesario aclarar que para llevar a cabo el trabajo que se presenta en esta memoria se ha podido utilizar un número muy elevado de animales gracias a las siguientes circunstancias favorables:

i) a que en el departamento de Anatomía de la Facultad de Veterinaria de Madrid se dispone de manera periódica de un número indeterminado de perros para la docencia práctica reglada de las asignaturas de la especialidad,

ii) a que, por parte de numerosos compañeros de clínicas privadas de Madrid y su provincia y de los responsables del Centro de Protección Animal de Valdemoro, se nos facilitaron animales que, por unos motivos u otros, debían ser sometidos a eutanasia, sin que en ningún caso la causa de tal decisión afectase a la cavidad abdominal y pelviana,

iii) a que se dispuso de mucho tiempo para conseguir un número de animales que a la hora de establecer cualquier tipo de conclusión fuese representativo; ese número finalmente fue de 116 animales adultos, machos y hembras, de distintas razas y mestizos, y de tamaño pequeño, mediano y grande; el número total de “medias-pelvis” estudiadas fue de 232.

La preparación de los animales se hizo en todos los casos de manera idéntica para lo cual se estableció un protocolo de actuación consistente en lo que dicta la técnica anatómica convencional en cuanto a la técnica de inyecciones vasculares se refiere. A continuación se procedió a la recogida de información que se llevó a cabo mediante el proceder habitual en anatomía, es decir la disección y microdisección. En el caso particular del estudio de la permeabilidad de la arteria umbilical se recurrió a completar el método con cortes histológicos efectuados a distinto nivel en la citada arteria. Por lo tanto, la coherencia de la metodología empelada se adaptaba a los requerimientos que un trabajo de esta naturaleza requería.

Una vez definido el modelo con el cual establecer diferencias, los objetivos concretos del estudio consistieron en definir, con la mayor precisión posible, las variaciones anatómicas de la arteria ilíaca interna y de sus tres ramas: el vaso que irriga la pared de la cavidad pelviana o arteria glútea caudal, el vaso que irriga las vísceras de la propia cavidad o arteria pudenda interna, y el vaso –supuestamente atrófico en el perro– que después del nacimiento evoluciona a ligamento redondo de la vejiga o arteria umbilical.

Los resultados finales del estudio realizado dieron lugar a la estructuración de cuatro manuscritos, uno para cada una de las tres arterias y otro final dedicado a las variaciones del conjunto vascular perineal. Los cuatro manuscritos fueron remitidos para su evaluación al consejo editorial de revistas de la especialidad, dos de ellos aceptados para su publicación y los otros dos –que se enviaron más tarde– están pendientes de decisión. Como quiera que la relación entre los manuscritos sea evidente no parece necesario hacer ningún tipo de comentario relativo a la coherencia que guardan entre sí las publicaciones aportadas, y de los manuscritos pendientes de decisión.

3. PUBLICACIONES

Los resultados obtenidos en el trabajo desarrollado durante el periodo dedicado a la elaboración de la tesis doctoral han dado lugar hasta el momento a dos publicaciones, que se adjuntan a continuación, relativas a las variaciones anatómicas de la arteria glútea caudal y de la arteria pudenda interna del perro adulto.

3.1. **Anatomical variations of the blood vascular system, in veterinary medicine. The internal iliac artery of the dog. Part one.**

ANATOMIA HISTOLOGIA EMBRYOLOGIA
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Anatomia, Histologia, Embryologia

ORIGINAL ARTICLE

Anatomical Variations of the Blood Vascular System in Veterinary Medicine

The Internal Iliac Artery of the Dog: Part One

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With 6 figures and 4 tables

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We dedicate this manuscript to Joaquín Camón, former full Professor of Anatomy and Embryology, who died on 10th March 2009.

Summary

Traditional veterinary anatomical models describe the branches of the caudal gluteal artery as the iliolumbar, cranial gluteal, lateral caudal, satellite of the ischiatic nerve and dorsal perineal arteries. However, some classical veterinary anatomy textbooks often indicate variations the general organization of the arterial tree, without giving any pattern of origin or illustrations of the different branching. The aim of this study was to investigate the presumptive variability of the caudal gluteal artery. Two hundred and thirty-two pelvic halves from 116 adult dogs were examined. Twelve anatomical variations were found, nine occurring in more than 5% of the dogs, and three in <5%. A 'long-type' internal iliac artery, which means short caudal gluteal and internal pudendal arteries, was identified, while a 'perineal trunk' was observed as an interesting arterial variation. If the caudal segment alone is taken into consideration, identical vascular patterns in both hemi-pelvises are found in 17% of the dogs. Significant statistical correlation was found for four different types of anatomic variations and gender, two types of variations and body size, one type of variation for body side and one type of variation for head shape.

Introduction

Anatomical variations of the blood vascular system (AVBVS) are considered as modifications of the vessels when compared to an established pattern. Such modifications, which in the present work refer exclusively to arteries, can affect vessels, particularly their size, origin, course and relationship, topography, branching and termination (Dubreuil-Chambardel, 1925; Testut and Latarjet, 1979). Although variations are described as anomalies, relationships between AVBVS and congenital malformations do not exist, which implies variations have no effect on the function of an organ under normal circumstances (Lippert and Pabst, 1985). Nevertheless, knowing their occurrence is of great importance in medicine (Subotich et al., 2009) and is crucial for surgeons (Damen et al., 2013; Goren et al., 2013; Moak et al., 2013).

In human medicine, AVBVS are described for virtually all body regions, with some areas studied in great detail. Examples include the base of the brain (Umansky et al., 1988; Stefani et al., 2000; Uchino et al., 2006), heart (Rou et al., 1975; Amico and Castorina, 2001; Pejković et al., 2008), kidney (Günenç and Denk, 2006), liver (De Cecco et al., 2009), gastrointestinal tract (Nassar et al., 2012) and the limbs (Ramírez and González, 2012; Sananpanich et al., 2013; Vázquez et al., 2013).

In contrast, there are fewer publications in veterinary medicine that focus on AVBVS with several of them specifically dealing with the same topic (Gomercić and Babic, 1972; Steiner et al., 1983; Zimmermann et al., 1989). However, some classical veterinary anatomy textbooks (Barone, 1996; Evans and de Lahunta, 2013) often indicate variations in the general organization of the arterial tree, without giving any pattern of origin or illustrations of the different branching.

The purpose of our research is to describe the diversity of variations in the internal iliac artery (IIA) of the dog. This study describes those variations found in the caudal gluteal artery (CGA). The reason for choosing AVBVS is the presumption that in future veterinarians specializing in surgery and reproduction will require this detailed information.

Material and Methods

The 116 dogs used in this study came from dissecting and post-mortem rooms. All animals were legally procured in accordance with the regulations and laws of the European Union (Directive 86/609/EEC) and Spain (RD 223/1998) for the care, use and housing of animals in research. The study was approved by the Complutense University of Madrid Bioethics Committee. Due to the high number of cross-breeds, dogs were grouped according to their head shapes or weight into three categories.

Using traditional anatomical techniques, the specimens studied were prepared and injected with coloured natural latex. The IIA and its major branches were exposed, and photographs and drawings were made systematically. During the entire process of dissection, special attention was paid to the origin and variations of the arteries, and the data were recorded with the highest possible accuracy. The traditional anatomical model considers the IIA gives off the umbilical, internal pudendal and caudal gluteal arteries, and the CGA branches are the iliolumbar, cranial gluteal, lateral caudal, satellite of the ischiatic nerve and dorsal perineal arteries. The variations described are schematically represented according to the conventional system used in human anatomy (Fig. 1).

The chi-squared test for independence or homogeneity was used to analyse differences in sex, side of the body, profile and size, and the results were considered statistically significant when $P \leq 0.05$.

Results

A total of 232 hemi-pelvises belonging to 116 adult dogs, 58 males and 58 females were examined. The number of dogs in each category was as follows: (1) head shape: 15 brachycephalic, 90 mesaticephalic and 11 dolichocephalic dogs and (2) weight: 31 small (<6 kg), 23 medium (7–20 kg) and 62 big (>20 kg) dogs. The findings described were observed during the entire phase of preparation of the anatomical specimens, and final results are shown in Fig. 2. The model chosen to make the pertinent comparisons is represented in Fig. 3.

The most significant anatomical variations of the CGA are presented in two different segments divided at the level of the caudal border of the sacral bone.

The first anatomical variation of the cranial segment (Fig. 4a) involves the origin of the CGA which relocates caudally to the level of the third sacral vertebrae. In these cases, the IIA is considerably longer than usual; that is, the length of the CGA and the internal pudendal artery is reduced, and the iliolumbar and cranial gluteal arteries stem from a common trunk of the IIA (Fig. 4b, Table 1-1.2). Likewise, it is also possible to find a common trunk to the same arteries arising from the CGA (Fig. 4c, Table 1-1.3). Finally, another variation observed in the cranial segment concerns the origin of segmental arteries (rami sacrales) which arise from the CGA (Fig. 4d, Table 1-1.4).

The anatomical variations of the caudal segment (Fig. 5a) are obvious and repetitive considering the selected model (Fig. 3, type A.1 in Table 2-2.1). The origin of the dorsal perineal artery varies as follows: (1) at the level of the lateral caudal artery (Fig. 5b, type A.2 in Table 2-2.2), (2) relocates cranially to the origin of the lateral caudal artery (Fig. 5c, type A.3 in Table 2-2.3) and (3) both the dorsal perineal and lateral caudal arteries stem from a common trunk arising from the CGA (Fig. 5d, type A.4 in Table 2-2.4).

A further variation occurs due to the existence of an additional vessel that will be described as a 'perineal trunk' where the dorsal perineal artery does not take origin directly from the CGA but from a common trunk (Fig. 6). The level of origin of the perineal trunk varies as follows: (1) approximately at the normal level of the dorsal perineal artery (Fig. 6b, type A.5 in Table 2-2.5), (2) at the level of the lateral caudal artery (Fig. 6c, type A.6 in Table 2-2.6), (3) located cranial to the origin of the lateral caudal artery (Fig. 6d, type A.7 in Table 2-2.7) and (4) shares a common trunk with the lateral caudal artery (Fig. 6e, type A.8 in Table 2-2.8). The perineal trunk constantly courses together with the superficial perineal nerve and supplies the skin, subcutaneous and adipose tissues of the perineal region. Perineal trunk symmetry between the right and left sides was observed in 39 cases (17%; Table 4).

Two more isolated cases show particular anatomical variations (data not shown in Table 2). In specimen 34 (male, left side), the lateral caudal artery arises from the internal pudendal artery, while in specimen 71 (female, right side), the lateral caudal artery together with the perineal trunk stems from the internal pudendal. Data and statistical analyses are recorded in Tables 1–4.

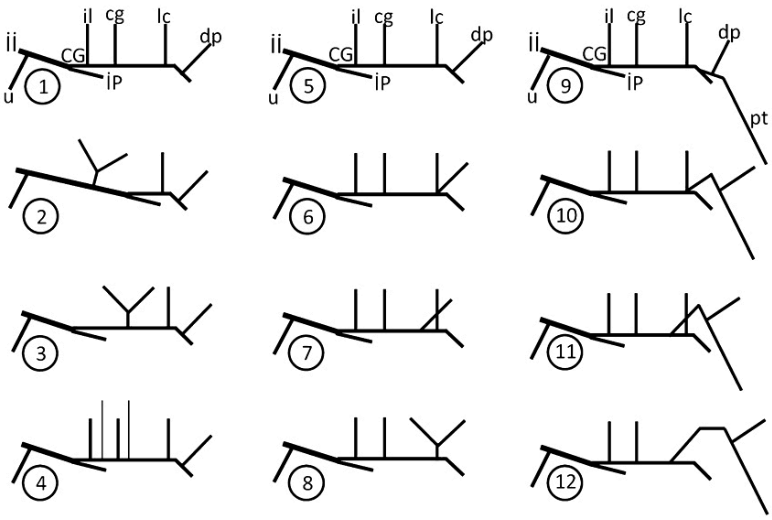

Fig. 1. Schematic representation which summarizes the anatomical variations of the caudal gluteal artery. 1–4 cranial segment; 5–8 caudal segment, dorsal perineal artery; and 9–12 caudal segment, perineal trunk. CG: caudal gluteal; cg: cranial gluteal; dp: dorsal perineal; ii: internal iliac; il: iliolumbar; iP: internal pudendal; lc: lateral caudal; pt: perineal trunk; u: umbilical.

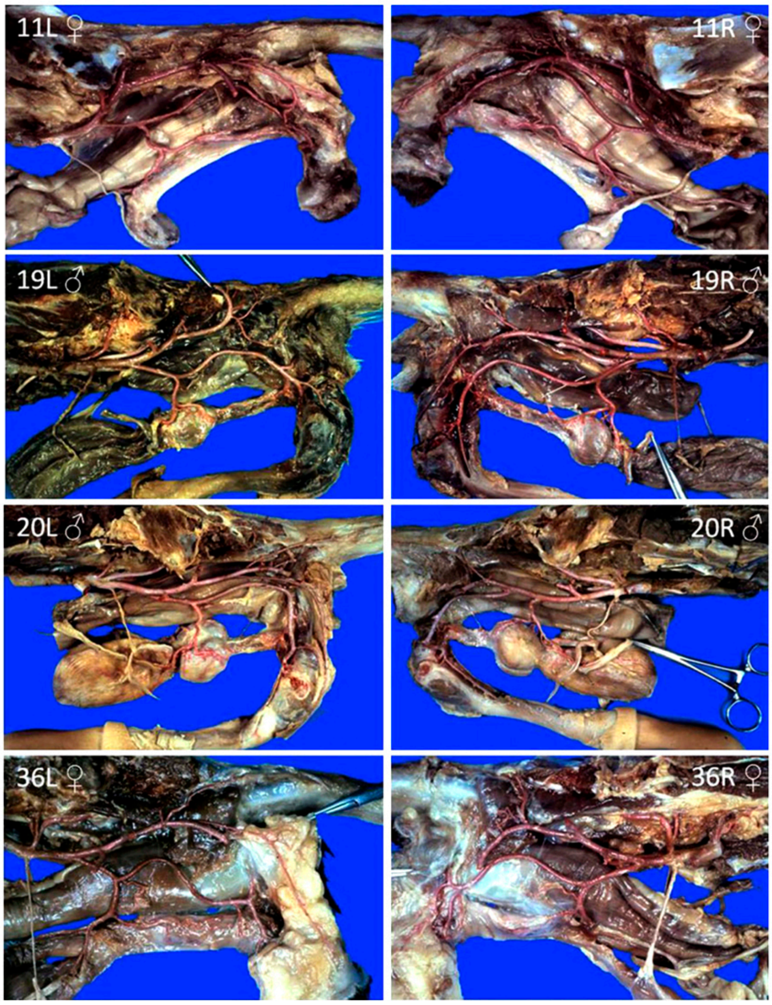

Fig. 2. Macrophotographs of eight hemi-pelvises, left and right sides, showing the final results of the anatomical preparations.

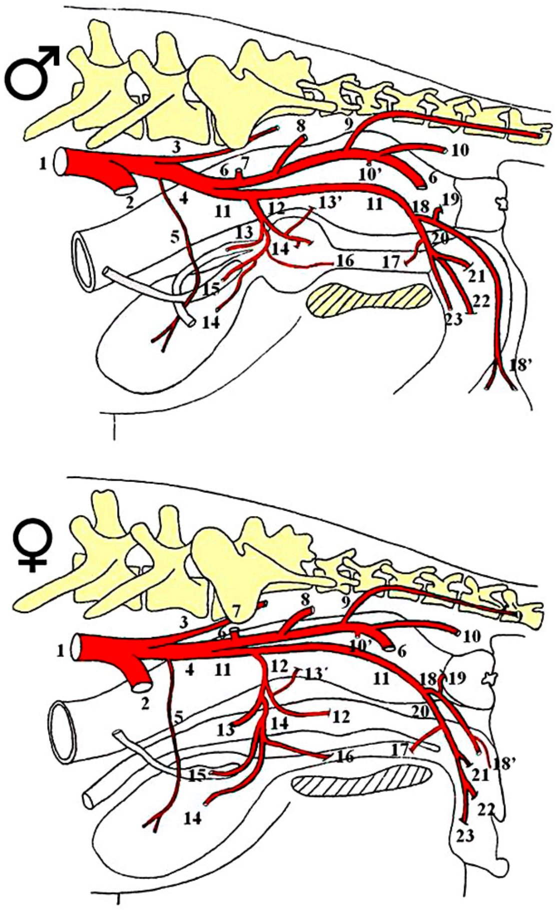

Fig. 3. Presumptive anatomical model used as reference for the general distribution and major branches of the internal iliac artery in male and female dogs. 1 Abdominal aorta; 2 external iliac; 3 median sacral; 4 internal iliac; 5 umbilical; 6 caudal gluteal; 7 iliolumbar; 8 cranial gluteal; 9 lateral caudal; 10 dorsal perineal; 10′ satellite of the ischiatic nerve; 11 internal pudendal; 12 prostatic/vaginal; 13 ductus deferens/uterine; 13′ middle rectal; 14 caudal vesical; 15 urethral branch; 16 urethral branch; 17 urethral; 18 ventral perineal; 18′ dorsal scrotal branch/dorsal labial branch; 19 caudal rectal; 20 artery of the penis/clitoris; 21 bulb of the penis/vestibular bulb; 22 deep artery of the penis/clitoris; 23 dorsal artery of the penis/clitoris (Original drawing by J. Camón).

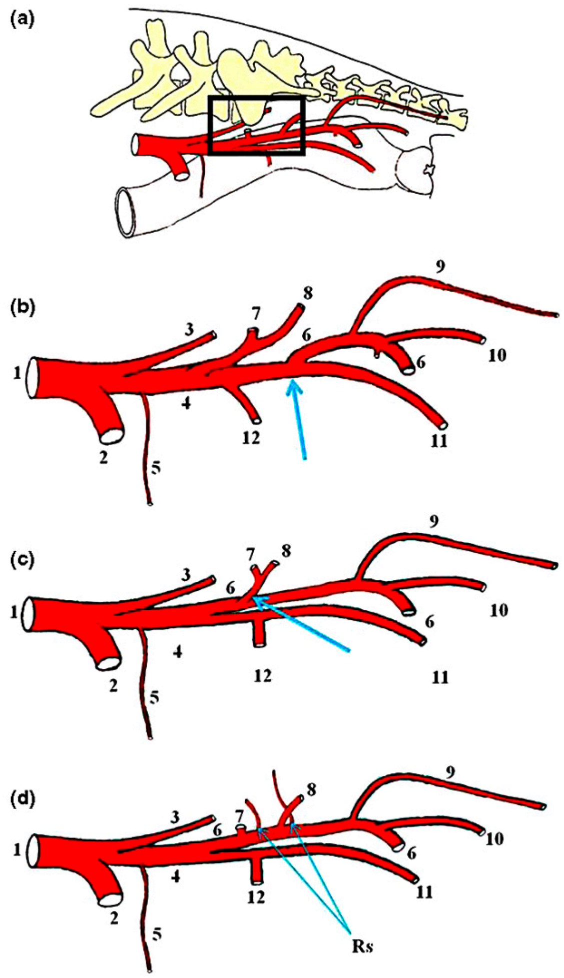

Fig. 4. Cranial segment of the caudal gluteal artery (a) and its anatomical variations (arrows): internal iliac artery long type (b), common trunk to iliolumbar and cranial gluteal arteries (c), and rami sacrales arising from the caudal gluteal artery (d). Both (b) and (c) have common trunks to the same vessels, that is iliolumbar and cranial gluteal arteries. This trunk originates from internal iliac artery long type (B) or from the cranial gluteal artery (c). Numbers correspond to the legend of Fig. 3.

Discussion

Selection of a reference model from the human literature for this study is of critical importance. Despite the existence of other sources (Lippert and Pabst, 1985; Bergman et al., 2006), work by the Japanese anatomist Buntaro Adachi (Adachi, 1928) is commonly considered the universal reference model for vascular anatomy. Although his work is written in German, it is easy even for non-German speakers to follow as every vascular description is illustrated with a schematic representation of the vessels.

Considering the anatomical variations of the IIA, knowledge of which is highlighted by obstetricians (Terek et al., 2004; Bleich et al., 2007), the first accurate classification was made by Jastchinski (Jastchinski, 1891) in Polish subjects, and later modified by Adachi (1928) in Japanese subjects. Similar investigations on different ethnic groups (Braithwaite, 1952; Roberts and Krishingner, 1967) resulted in modifications to the Adachi IIA classification. Following a conventional anatomical method, Yamaki et al. (1998)

Table 1. Data for anatomical variations concerning the cranial segment of the CGA considering pelvic halves

	Sex		Side		Profile			Size		
	Male	Female	Left	Right	Brach	Mesa	Dolich	Small	Med	Big
T number	116	116	116	116	30	180	22	62	46	124
1.1	Traditional anatomical model. Number of cases: 196 = 84.48%									
n	95	101	96	100	24	152	20	58	36	102
%	81.90	87.07	82.75	86.21	80.00	84.44	90.90	93.54	78.26	82.25
1.2	Internal iliac artery. Long type. [a]Number of cases: 12 = 5.17%									
n	9	3	6	6	4	8	0	0	7	5
%	7.76	2.59	5.17	5.17	13.33	4.44	0	0	15.22	4.03
1.3	Common trunk to iliolumbar and cranial gluteal arteries.[b] Number of cases: 4 = 1.72%									
n	3	1	1	3	1	3	0	2	1	1
%	2.59	0.86	0.86	2.59	3.33	1.67	0	3.23	2.17	0.81
1.4	Rami sacrales arising from the caudal gluteal artery. Number of cases: 20 = 8.62%									
n	9	11	13	7	1	17	2	2	2	16
%	7.76	9.48	11.21	6.03	3.33	9.44	9.09	3.23	4.35	12.90

CGA, caudal gluteal artery; *n*, Number of cases; %, percentages in relation to the total specimens.
[a]Iliolumbar and cranial gluteal arteries arise from a common trunk originating in the internal iliac artery long type.
[b]Iliolumbar and cranial gluteal arteries arise from a common trunk originating in the cranial gluteal artery.

Table 2. Data for anatomical variations concerning the caudal segment of the CGA considering pelvic halves

	Sex		Side		Profile			Size		
	Male	Female	Left	Right	Brach	Mesa	Dolich	Small	Med	Big
T number	116	116	116	116	30	180	22	62	46	124
2.1	Caudal gluteal artery. Type A.1. Number of cases: 71 = 30.60%									
n	44	27	34	37	9	58	4	23	14	34
%	37.93	23.28	29.31	31.90	30	32.22	18.16	37.10	30.43	27.42
2.2	Caudal gluteal artery. Type A.2. Number of cases: 23 = 9.91%									
n	18	5	16	7	2	20	1	5	5	13
%	15.52	4.31	13.79	6.03	6.67	11.11	4.55	8.06	10.87	10.48
2.3	Caudal gluteal artery. Type A.3. Number of cases: 17 = 7.33%									
n	9	8	10	7	4	13	0	5	3	9
%	7.76	6.89	8.62	6.03	13.33	7.22	0	8.06	6.52	7.26
2.4	Caudal gluteal artery. Type A4. Number of cases: 26 = 11.21%									
n	17	9	13	13	3	21	2	7	3	16
%	14.66	7.76	11.21	11.21	10.00	11.67	9.10	11.29	6.52	12.90
2.5	Caudal gluteal artery. Type A.5. Number of cases: 21 = 9.05%									
n	4	17	13	8	2	17	2	6	4	11
%	3.45	14.66	11.21	6.90	6.67	9.44	9.10	9.68	8.70	8.87
2.6	Caudal gluteal artery. Type A.6. Number of cases: 21 = 9.05%									
n	4	17	10	11	4	15	2	5	6	10
%	3.45	14.66	8.62	9.48	13.33	8.33	9.10	8.06	13.04	8.06
2.7	Caudal gluteal artery. Type A.7. Number of cases: 26 = 11.21%									
n	9	17	11	15	3	17	6	7	4	15
%	7.76	14.66	9.48	12.93	10.00	9.44	27.27	11.29	8.70	12.10
2.8	Caudal gluteal artery. Type A.8. Number of cases: 25 = 10.78%									
n	10	15	8	17	2	18	5	4	7	14
%	8.62	12.93	6.90	14.66	6.67	10.00	22.73	6.45	15.22	11.29

CGA, caudal gluteal artery; *n*, Number of cases; %, percentages in relation to the total specimens.

proposed a new classification of the IIA. Recently, a new approach to investigate the IIA using different imaging modalities has been introduced (Bilhim et al., 2011). These various investigations illustrate specific models which describe in detail the general organization of the arterial system and its most frequent variations in humans. It is

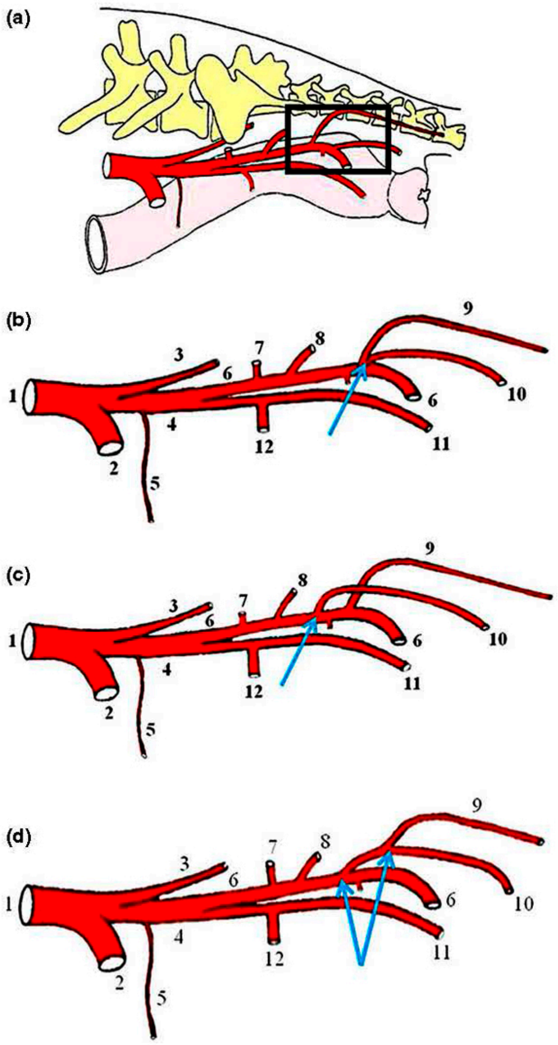

Fig. 5. Caudal segment of the caudal gluteal artery (a) with anatomical variations in the origin of the dorsal perineal artery (arrows) in relation to the presumptive model: Type A.2, at the level of the lateral caudal artery (b); Type A.3, cranial to the level of the lateral caudal artery (c); Type A.4, common trunk (d). Numbers correspond to the legend of Fig. 3.

interesting to note that to avoid any confusion, the majority of the publications related to anatomical variations of the IIA in humans specify ethnic groups: Polish (Jastchinski, 1891), Japanese (Adachi, 1928; Yamaki et al., 1998), American Whites and Negroes (Ashley and Anson, 1941), Romanian (Fatu et al., 2006) and south Indian (Naveen et al., 2011).

The study of the AVBVS in veterinary medicine is quite complex, due to the variety of domesticated mammals (cows, sheep, goats, pigs, horses, cats and dogs), and

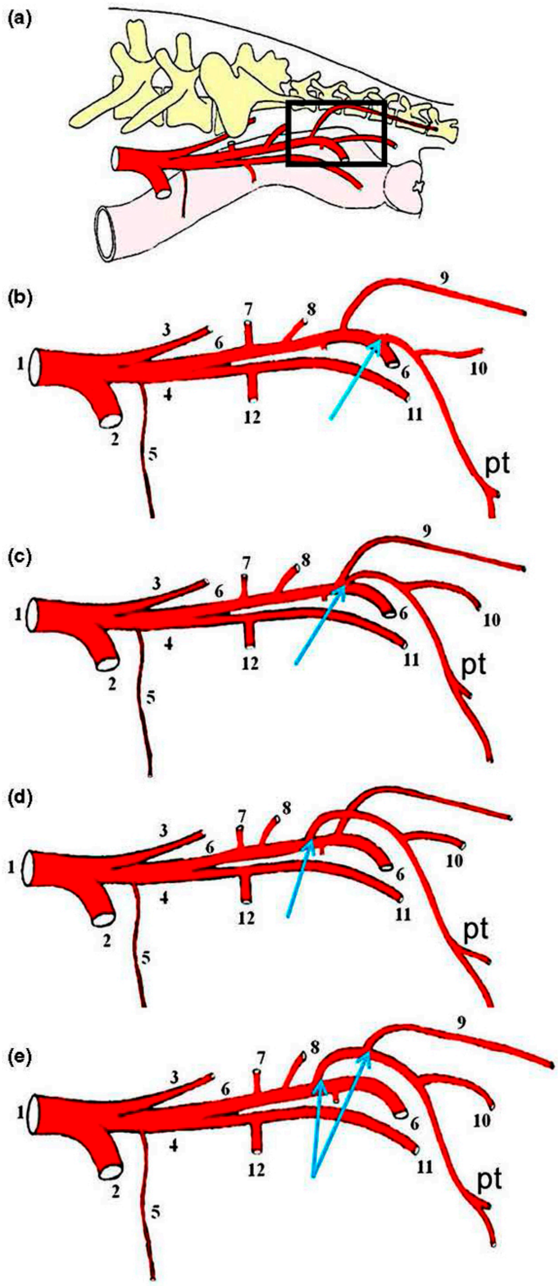

Fig. 6. Caudal segment of the caudal gluteal artery (a) with anatomical variations in relation to the origin of the perineal trunk (arrows): (i) Type A.5, it is approximately at the same place as the dorsal perineal artery (b); (i) Type A.6, it corresponds to the origin of the lateral caudal artery (c); (i) Type A.7, it is displaced forward and located cranially at the origin of the lateral caudal artery (d); (i) Type A.8, it is also located at the origin of the lateral caudal artery, but in this case, the artery arises from the trunk (e). Numbers correspond to the legend of Fig. 3.

Table 3. Chi-squared data in relation to sex, side, profile and size; $P \leq 0.05$ significant

Degrees of freedom	T number	Sex 1	Side 1	Profile 2	Size 2
1.1 Pearson chi-square	1.1	1.184	0.526	1.153	5.713
1.1 *P*-value	1.1	0.276	0.468	0.562	0.057
1.2 Pearson chi-square	1.2	3.164	0.000	5.468	13.173
1.2 *P*-value	1.2	0.075	1	0.065	0.001
1.3 Pearson chi-square	1.3	1.018	1.018	2.994	1.496
1.3 *P*-value	1.3	0.313	0.313	0.224	0.473
1.4 Pearson chi-square	1.4	0.219	1.970	1.226	6.244
1.4 *P*-value	1.4	0.640	0.160	0.542	0.044
2.1 Pearson chi-square	2.1	5.865	0.183	1.826	1.823
2.1 *P*-value	2.1	0.015	0.669	0.401	0.402
2.2 Pearson chi-square	2.2	8.156	3.909	1.353	0.330
2.2 *P*-value	2.2	0.004	0.048	0.508	0.848
2.3 Pearson chi-square	2.3	0.063	0.571	3.336	0.094
2.3 *P*-value	2.3	0.801	0.450	0.189	0.954
2.4 Pearson chi-square	2.4	0.063	0.000	0.181	1.374
2.4 *P*-value	2.4	0.801	1.000	0.913	0.503
2.5 Pearson chi-square	2.5	8.849	1.309	0.241	0.041
2.5 *P*-value	2.5	0.003	0.252	0.886	0.979
2.6 Pearson chi-square	2.6	8.849	0.052	0.781	1.111
2.6 *P*-value	2.6	0.003	0.819	0.677	0.574
2.7 Pearson chi-square	2.7	2.772	0.693	6.312	0.391
2.7 *P*-value	2.7	0.096	0.405	0.043	0.823
2.8 Pearson chi-square	2.8	1.121	3.631	3.908	2.184
2.8 *P*-value	2.8	0.290	0.057	0.142	0.336

1.1 1.4, Data corresponding to Table 1.
2.1 2.8, Data corresponding to Table 2.

Table 4. Data for vascular symmetry pattern in bilateral hemi-pelvises with regard to each type of the caudal segment of the CGA: A1 A8

	A1	A2	A3	A4	A5	A6	A7	A8
n	18	1	2	4	1	3	4	6
%	7.75	0.43	0.86	1.72	0.43	1.29	1.72	2.59

CGA, caudal gluteal artery; *n*, Number of cases; %, percentages in relation to the total specimens.

to the variety of breeds in each species. In particular, in dogs, there is no doubt that contemporary anatomical text books describe with precision the most important variations concerning the IIA's anatomy (Getty, 1975; Schummer et al., 1981; Barone, 1996; Dyce et al., 2010; Evans and de Lahunta, 2013). Therefore, a reasonable option is to use the guidelines established by the Nomina Anatomica Veterinaria (International Committee on Veterinary Gross Anatomical Nomenclature, 2012) as a model of the general organization and distribution of the canine IIA. Furthermore, this model is logically structured and can be easily followed by viewing the 'official illustrations' made by Paul Simoens (Constantinescu and Schaller, 2011). If we compare that model to our own findings, several anatomical variations can clearly be identified, of which the most relevant should be mentioned.

Regarding the origin of the CGA and the origin of its major branches, the twelve anatomical variations found are clear evidence of the diversity of variations within the arterial system (Tables 1 and 2). Only 31% of the studied cases corresponding to the caudal segment were normal, that is were identical to the official model (Table 2, type 2.1).

On the other hand, in 5% of the hemi-pelvises, we have observed the IIA's long type (Table 1, 1.2), which is typical of the normal branching found in swine and ruminants (Nitschke and Preuss, 1971). We consider the existence of the perineal trunk in 40% of the specimens analysed in a relevant finding of our study (Table 2, types A.5–A.8). There is a direct relationship between the presence of the perineal trunk and the variations of the ventral perineal artery. Traditionally, the origin of the ventral perineal artery is described in the internal pudendal artery as a terminal branch giving off the caudal rectal artery afterwards. When a perineal trunk is present, the ventral perineal artery originates in the trunk, and the ventral perineal region is supplied by the caudal gluteal artery (L. Avedillo, N. Martín-Alguacil, T. Donnelly, I. Salazar, manuscript in preparation).

According to Table 3, the anatomical variations of types 2.1 and 2.2 were significant in males, and of types 2.5 and 2.6 in females. In the same caudal segment of the CGA, the values for the left side were significant in type 2.2, and for the dolichocephalic dogs in type 2.7. However, in the cranial segment, the significance was only related to size: the long type occurred in medium size dogs (type 1.2), and the 'rami sacrales' type in big dogs (type 1.4).

Equal vascular pattern in either hemi-pelvises, that is symmetry between right and left sides, was observed in the caudal segment of the CGA in 17% of the studied cases. When comparing the different types described herein (A1–A8), symmetry was higher in type A1. When the perineal trunk was present (A.5–A.8), the symmetry was slightly higher (data not shown) than in those cases presenting an independent dorsal perineal artery (A.2–A.4; Table 4).

Apparently, no anatomical variations found have a logical *a priori* explanation. In general, the reasons for the presence of any AVBVS should be sought in the evolution of the vascular system during development, and in the changes that occur from embryo to foetus to neonate (Rüsse and Sinowatz, 1994; Sadler, 2012). Therefore, it is likely that AVBVS will be more frequent in those anatomical regions in which changes in development are more significant. In certain circumstances, the AVBVS are so important that they may constitute true anomalies or malformations (Hopwood et al., 1987; Menzel and Distl, 2011).

In conclusion, anatomical variations of the caudal gluteal artery occur with regard to its origin and that of its major branches. A proposal to classify these types of modifications is presented herein.

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3.2. **Anatomical variations of the blood vascular system in veterinary medicine. The internal iliac artery of the dog. Part two.**

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ORIGINAL ARTICLE

Anatomical Variations of the Blood Vascular System in Veterinary Medicine. The Internal Iliac Artery of the Dog. Part Two

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Summary

The aim of this study was to investigate the variability of the internal pudendal artery. Two hundred and thirty-two pelvic halves from 116 adult dogs were examined. Twenty-six anatomical variations were found, thirteen occurring in more than 5% of the dogs. Anatomical variations were grouped in relation to the origin of the prostatic/vaginal arteries, middle rectal artery, urethral artery, ventral perineal and caudal rectal arteries. The chi-squared test was used to analyse differences in sex, side of the body, profile and size, and the results were considered statistically significant when $P \leq 0.05$. An identical vascular pattern in both hemipelvises was found for most of the anatomical variations described.

Introduction

Anatomical variations of the blood vascular system (AVBVS) are considered as modification of the vessels when compared to an established pattern (Avedillo et al., 2014). Such modifications, which in the present work refer exclusively to arteries, can affect vessels, particularly their size, origin, course and relationship, topography, branching and termination (Dubreuil-Chambardel, 1925; Testut and Latarjet, 1979). Although variations are also described as anomalies, relationships between AVBVS and congenital malformations do not exist, which implies variations have no effect on the function of an organ under normal circumstances (Winslow, 1883; Lippert and Pabst, 1985). Nevertheless, knowing their occurrence is of great importance in medicine and surgery.

Despite the existence of other sources (Dubreuil-Chambardel, 1925; Lippert and Pabst, 1985; Bergman et al., 2006), work by the Japanese anatomist Buntaro Adachi (Adachi, 1928) is commonly considered the universal reference model for human vascular anatomy. The anatomical variations of the internal iliac artery (IIA) are highlighted by different authors (Ledwich, 1887; Redfern, 1850; Parsons and Keith, 1897; Levi, 1902; Lipshutz, 1918; Braithwaite, 1952; Terek et al., 2004; Bleich et al., 2007).

In contrast, there are fewer publications in veterinary medicine that focus on AVBVS. However, some classical veterinary anatomy textbooks (Getty, 1975; Schummer et al., 1981; Barone, 1996; Evans and de Lahunta, 2013) often indicate variations in the general organization of the arterial tree, without giving any pattern of origin or illustrations of the different branching. There are some occasional publications dealing with different aspects of arterial variations (Mannu, 1914; Barone, 1954; Franke, 1958; Vitums, 1962; Cuthberstson and Gilfillan, 1964; Kowatschev, 1968) or dealing with specific organs such as the pancreas (Gomerćić and Babic, 1972; Steiner et al., 1983; Zimmermann et al., 1989).

The purpose of our research is to describe the diversity of variations in the IIA of the dog. This study describes those variations found in the internal pudendal artery (IPA). The reason for choosing AVBVS is the presumption that in the future veterinarians specializing in surgery and reproduction will require this detailed information.

Material and Methods

A detailed description of the procedure used for the present work is referred in Part 1 (Avedillo et al., 2014). This study describes the variations of the IPA branches. The traditional anatomical model considers the IIA giving off the umbilical artery, the IPA and caudal gluteal artery (CGA), and the IPA branches are the prostatic/vaginal, urethral, ventral perineal arteries, and the artery of the penis/clitoris. The variations described are schematically represented in Fig. 1.

The chi-squared test for independence or homogeneity was used to analyse differences in sex, side of the body, profile and size, and the results were considered statistically significant when $P \leq 0.05$.

Results

A total of 232 hemipelvises belonging to 116 adult dogs, 58 males and 58 females, were examined. Dogs were classified according to the head shape (brachycephalic, mesaticephalic and dolichocephalic) and weight (small < 6 kg, medium 7–20 kg and big > 20 kg). The findings observed and the final results are shown in Fig. 2. The model chosen to make the pertinent comparisons is represented in Fig. 3.

Prostatic/vaginal artery

The first anatomical variations of the prostatic/vaginal artery involve the direct origin of this artery from the IIA. In these cases, the IIA is considerably longer than usual (IIA long type) (Fig. 4a, Table 1, type 1.1). Alternatively, the prostatic/vaginal artery may arise from the umbilical artery (Fig. 4b, Table 1, type 1.2). Symmetry between right and left sides was observed in 6 cases (3%; Table 9).

Middle rectal artery

The origin of the middle rectal artery varies as follows: (1) at different levels of the prostatic/vaginal artery (Fig. 5a–e, Table 3, types 3.1–3.5); (2) from the artery of the ductus deferens/uterine artery (Fig. 5f, Table 3, type 3.6); (3) from the IPA (Fig. 5g, Table 3, type 3.7); (4) from the CGA (Fig. 5h, Table 3, type 3.8); (5) from the long type IIA (data not illustrated, Table 3, type 3.9). (6) Some isolated cases show particular anatomical variations when the middle rectal artery is multiple (data not illustrated, Table 3, type 3.10) (see discussion). Symmetry between right and left sides was observed in 96 cases (41%; Table 9).

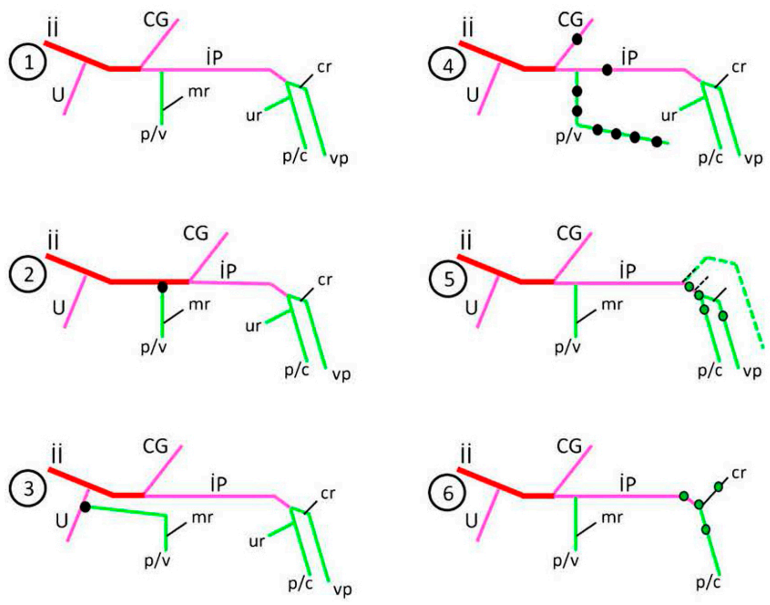

Fig. 1. Schematic representation which summarizes the anatomical variations of the internal pudendal artery. 1, presumptive anatomical model; 2 3, origin of the prostatic/vaginal arteries; 4, origin of the middle rectal artery; 5 6, origin of the ventral perineal and caudal rectal arteries. CG caudal gluteal; cr, caudal rectal; ●● internal iliac; ●P internal pudendal; mr, middle rectal; p/c, penis/clitoris; p/v, prostatic/vaginal; ur, urethral; vp, ventral perineal; U umbilical.

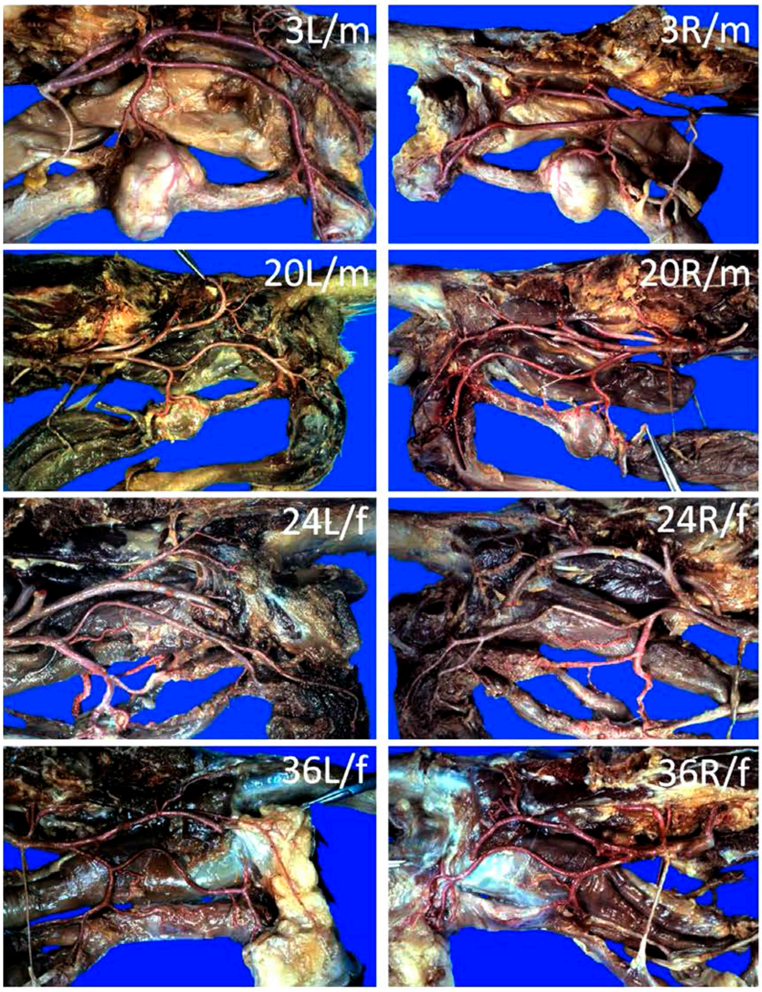

Fig. 2. Macrophotographs of eight hemipelvises, left and right sides, showing the final results of the anatomical preparations.

Urethral artery

The origin of the urethral artery varies as follows: (i) cranial (Fig. 6a, Table 5, type 5.1) or caudal to the origin of the ventral perineal artery (Fig. 6b, Table 5, type 5.2) or in common with it (Fig. 6c, Table 5, type 5.3); (ii) directly from the ventral perineal artery (Fig. 6d, Table 5, type 5.4); (iii) from the 'perineal trunk' as described in the discussion (data not illustrated, Table 5, type 5.5). Symmetry between right and left sides was observed in 55 cases (24%; Table 9).

Ventral perineal and caudal rectal arteries

The anatomical variations of these arteries concern: (i) three cases of independent origin of the ventral perineal and caudal rectal arteries (Fig. 7a–c, Table 7, types 7.1–7.3); (ii) the relationship between the origin of the caudal rectal and urethral arteries when the ventral perineal artery is not present (Fig. 7d–g, Table 7, types 7.4–7.7); (iii) the absence of the ventral perineal artery, caudal rectal artery (Fig. 7h, Table 7, type 7.8) and urethral artery (Fig. 7i, Table 7, type 7.9). Symmetry between right and left sides was observed in 45 cases (19%; Table 9). All data (Tables 1, 3, 5, 7 and 9) and the corresponding statistical analysis (Tables 2, 4, 6 and 8) are presented.

Discussion

Selection of a reference model from the human literature for this study is of critical importance. Several

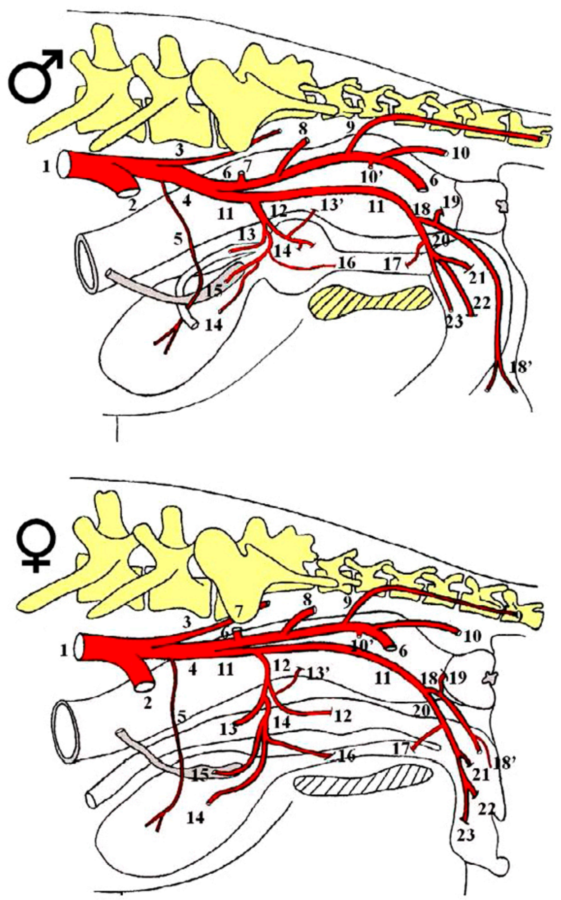

Fig. 3. Presumptive anatomical model used as reference for the general distribution and major branches of the internal iliac artery in male and female dogs. 1 Abdominal aorta; 2 external iliac; 3 median sacral; 4 internal iliac; 5 umbilical; 6 caudal gluteal; 7 iliolumbar; 8 cranial gluteal; 9 lateral caudal; 10 dorsal perineal; 10′ satellite of the ischiatic nerve; 11 internal pudendal; 12 prostatic/vaginal; 13 ductus deferens/uterine; 13′ middle rectal; 14 caudal vesical; 15 ureteral branch; 16 urethral branch; 17 urethral; 18 ventral perineal; 18′ dorsal scrotal branch/dorsal labial branch; 19 caudal rectal; 20 artery of the penis/clitoris; 21 bulb of the penis/vestibular bulb; 22 deep artery of the penis/clitoris; 23 dorsal artery of the penis/clitoris (original drawing by J. Camón).

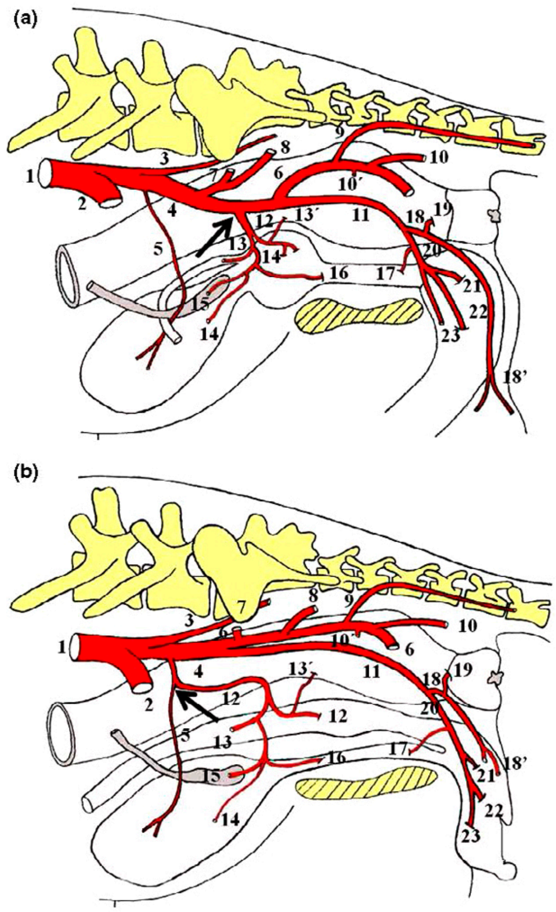

Fig. 4. Origin of the prostatic/vaginal arteries and their anatomical variations (a) the prostatic artery arises from the internal iliac artery long type (arrow). (b) The vaginal artery arises from the umbilical artery (arrow). Numbers correspond to the legend of Fig. 3.

investigations illustrate specific models which describe in detail the general organization of the arterial system and its most frequent variations in humans (Yamaki et al., 1998; Bilhim et al., 2011).

The study of the AVBVS in veterinary medicine is quite complex, due to the variety of domesticated mammals, and to the variety of breeds in each species. In particular, in dogs, there is no doubt that contemporary anatomical text books describe with precision the most important variations concerning IIA anatomy (Getty, 1975; Schummer et al., 1981; Barone, 1996; Dyce et al., 2010; Evans and de Lahunta, 2013). Therefore, a reasonable option is to use the guidelines established by the Nomina Anatomica Veterinaria (International Committee on Veterinary Gross Anatomical Nomenclature, 2012) as a model of general organization and distribution of the canine IIA. Furthermore, this model is logically structured and can be easily followed by viewing the ‘official illustrations’ made by Paul Simoens (Constantinescu and Schaller, 2011). In addition, the selected model has been completed with information included in some specialized publications (Preuss, 1959; Rauch, 1963; Gyürü and Kovács, 1967; Hodson, 1968; Nitschke and Preuss, 1971; Gościcka et al., 1977; Campos et al., 1984; Goldsmid et al., 1993; Stefanov, 2004). This is a praiseworthy attempt to unify criteria, which is not an easy task. If we

Table 1. Data of anatomical variations of the prostatic/vaginal artery considering pelvic halves

	Sex		Side		Profile			Size		
	Male	Female	Left	Right	Brach	Mesa	Dolich	Small	Med	Big
AVT	116	116	116	116	30	180	22	62	46	124
1.1	Origin of the P/VA directly from the IIA (long type). Figure 4a Number of cases: 12 = 5.17%									
n	9	3	6	6	4	8	0	0	6	6
%	7.76	2.59	5.17	5.17	13.33	4.44	0.0	0.0	13.04	4.83
1.2	Origin of the P/VA from the umbilical artery. Figure 4b. Number of cases: 8 = 3.45%									
n	1	7	4	4	0	8	0	4	0	4
%	0.86	6.03	3.45	3.45	0.0	4.44	0.0	6.45	0.0	3.23

AVT, anatomical variation type; IIA, internal iliac artery; P/VA, prostatic/vaginal artery; *n*, number of cases; %, percentages in relation to the total specimens.

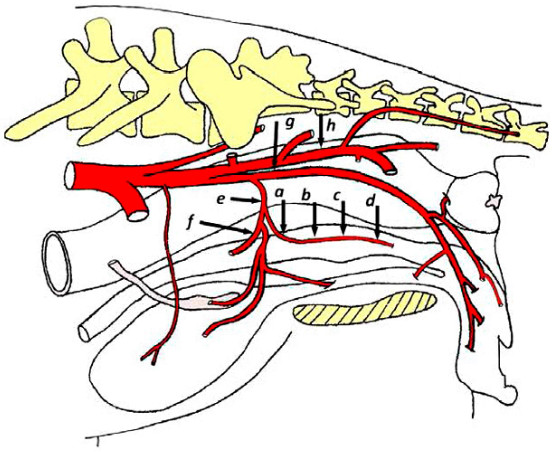

Fig. 5. Origin of the middle rectal artery and its anatomical variations (arrows) for female dogs, arising from: the vaginal artery (a e); arising from the uterine artery (f); arising from the internal pudendal artery (g); arising from the caudal gluteal artery (h). Numbers correspond to the legend of Fig. 3.

compare the model to our own findings, several anatomical variations can clearly be identified, of which the most relevant should be mentioned.

Anatomical variations of the CGA, which is the parietal branch of the IIA, have previously been studied (Avedillo et al., 2014). The IPA, which is the small visceral branch of the IIA, supplies part of the urogenital and digestive systems and is the aim of the present discussion. Age, gender, status of the reproductive system and frequent presence of pathological lesions in the territory supplied by the IPA may be relevant factors for the frequency of anatomical variations of the IPA (Wang et al., 2006; Sapierzyński et al., 2007; Martins et al., 2008; Leroy and Northrup, 2009; Van den Steen et al., 2012).

In 5% of the hemipelvises, we have observed the long type IIA, which is typical of the normal branching found in swine and ruminants (Nitschke and Preuss, 1971). In these cases, the prostatic/vaginal artery arises directly from the IIA (Fig. 4a; Table 1, type 1.1). Less frequent, in 3.5% of the hemipelvises, the prostatic/vaginal artery has its origin in the urethral artery (Fig. 4b; Table 1, type 1.2). Significant values were found for size (type 1.1;

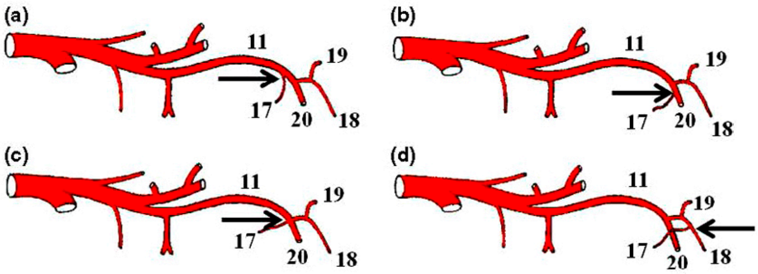

Fig. 6. Origin of the urethral artery and its anatomical variations (arrows), cranial (a) or caudal (b) to the level of the ventral perineal artery, arising at the same level of the ventral perineal artery (c), or arising directly from the ventral perineal artery (d). Numbers correspond to the legend of Fig. 3.

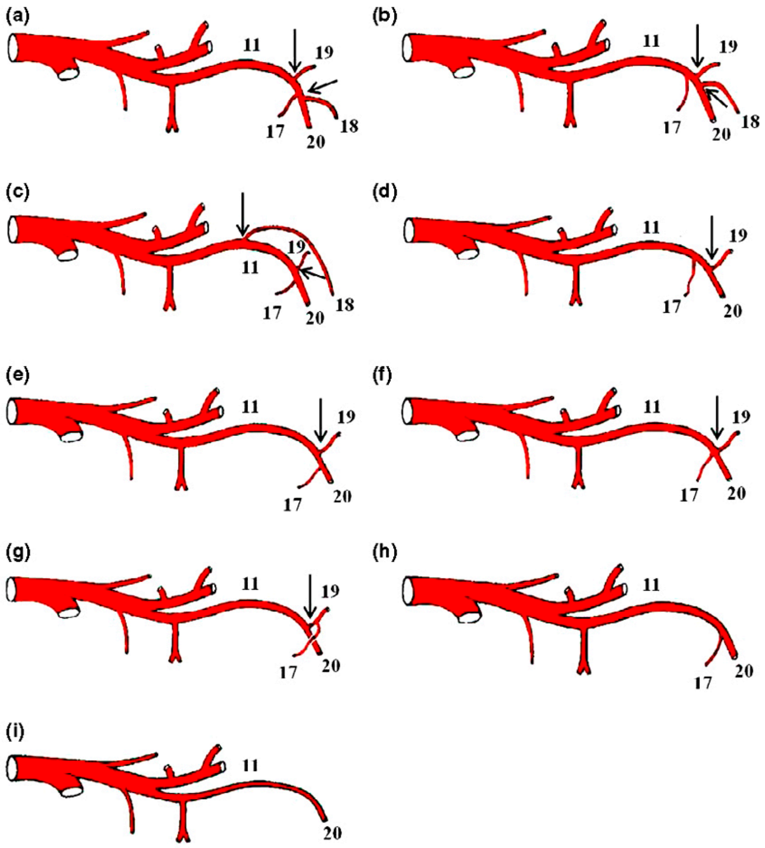

Fig. 7. Anatomical variations (arrows) in the origin of the ventral perineal (a-c) and caudal rectal (a-f) arteries. Note the relationship between the origin of the CRa and URa when the VPa is absent (d-g) and the absence of VPa, CRa (h) and URa (i). Numbers correspond to the legend of Fig. 3.

Table 2. Chi-squared data in relation to sex, side, profile and size. Data corresponding to Table 1

Degrees of freedom	T number	Sex 1	Side 1	Profile 2	Size 2
1.1 Pearson chi square	1.1	3.164	0.000	5.468	9.220
1.1 *P*-value	1.1	0.075	1.000	0.065	0.009**
1.2 Pearson chi square	1.2	4.661	0.000	2.394	3.341
1.2 *P*-value	1.2	0.031*	1.000	0.302	0.188

*P-value <0.05.
**P-value <0.01.

Table 2, 1.1 P-value) and gender (type 1.2; Table 2, 1.2 P-value).

It is interesting to mention that the origin of middle rectal artery is often represented by several small branches from the prostatic/vaginal artery (Getty, 1975). We found a multiple origin for this artery in 17 hemipelvises (7%); they were grouped as 'special cases' and included in Table 3, as variation 3.10, and we consider it a peculiar anatomical variation. The branching of the middle rectal artery represents another AVBVS in which four types were established (Wakui et al., 1993), and we have identified ten types (Table 3). The differences among results could be explained by the number (50 versus 116) and the gender of the specimens examined (only male, versus

Table 3. Data for anatomical variations concerning the IPA, MRa considering pelvic halves

	Sex		Side		Profile			Size		
	Male	Female	Left	Right	Brach	Mesa	Dolich	Small	Med	Big
T Number	116	116	116	116	30	180	22	62	46	124
3.1	Origin of MRa from P/Va, Figure 4, *type a*. Number of cases: 75 = 32.33%									
n	51	24	38	37	7	66	2	21	16	38
%	43.97	20.69	32.76	31.90	23.33	36.67	9.09	33.87	34.78	30.65
3.2	Origin of MRa from P/Va, Figure 4, *type b*. Number of cases: 39 = 16.81%									
n	18	21	13	26	5	31	3	11	9	19
%	15.52	18.10	12.21	22.41	16.66	17.22	13.64	17.74	19.57	15.32
3.3	Origin of MRa from P/Va, Figure 4, *type c*. Number of cases: 23 = 9.91%									
n	3	20	13	10	5	12	6	8	4	11
%	2.57	17.24	12.21	8.62	16.66	6.66	27.27	12.90	8.70	8.87
3.4	Origin of MRa from P/Va, Figure 4, *type d*. Number of cases: 4 = 1.72%									
n	0	4	4	0	0	4	0	1	1	2
%	0.0	3.45	3.45	0.0	0.0	2.22	0.0	1.61	2.17	1.61
3.5	Origin of MRa from P/Va, Figure 4, *type e*. Number of cases: 41 = 17.67%									
n	21	20	23	18	6	30	5	14	3	24
%	18.10	17.24	19.82	15.52	20	1.67	22.73	22.58	6.52	19.35
3.6	Origin of MRa from the artery of the ductus deferens/uterine, Figure 4, *type f*. Number of cases: 5 = 2.15%									
n	3	2	5	0	1	4	0	2	3	0
%	2.57	1.72	4.31	0.0	3.33	2.22	0.0	3.23	6.52	0.0
3.7	Origin of MRa from IPA, Figure 4, *type g*. Number of cases: 24 = 10.34%									
n	9	15	11	13	0	19	5	2	4	18
%	7.76	12.93	9.48	12.21	0.0	10.56	22.73	3.23	8.70	14.52
3.8	Origin of MRa from CGA, Figure 4, *type h*. Number of cases: 2 = 0.86%									
n	2	0	1	1	0	2	0	0	1	1
%	1.72	0.0	0.86	0.86	0.0	1.11	0.0	0.0	2.17	0.81
3.9	Origin of MRa from the long type IIA (not illustrated). Number of cases: 2 = 0.86%									
n	1	1	1	1	1	1	0	0	0	2
%	0.86	0.86	0.86	0.86	3.33	0.55	0.0	0.0	0.0	1.61
3.10	Special cases due to the MRa being multiple (not illustrated). Number of cases: 17 = 7.33%									
n	7	10	8	9	1	14	2	3	4	10
%	6.03	8.62	6.90	7.76	3.33	7.78	9.09	4.84	8.70	8.06

IPA, internal pudendal artery; MRa, middle rectal artery; P/Va, prostatic/vaginal artery; IIA, internal iliac artery; *n*, number of cases; %, percentages in relation to the total specimens.

Table 4. Chi-squared data in relation to sex, side, profile and size. Data corresponding to Table 3

Degrees of freedom	T Number	Sex 1	Side 1	Profile 2	Size 2
3.1 Pearson chi-square	3.1	14.363	0.200	8.088	0.355
3.1 *P*-value	3.1	0.000**	0.888	0.018*	0.837
3.2 Pearson chi-square	3.2	0.277	5.209	0.181	0.484
3.2 *P*-value	3.2	0.598	0.022*	0.914	0.784
3.3 Pearson chi-square	3.3	13.948	0.434	11.080	0.848
3.3 *P*-value	3.3	0.000**	0.510	0.004**	0.654
3.4 Pearson chi-square	3.4	4.070	3.861	1.176	0.063
3.4 *P*-value	3.4	0.044*	0.049*	0.555	0.966
3.5 Pearson chi-square	3.5	0.030	0.741	0.623	5.199
3.5 *P*-value	3.5	0.863	0.389	0.732	0.074
3.6 Pearson chi-square	3.6	0.204	5.110	0.686	7.228
3.6 *P*-value	3.6	0.651	0.024*	0.710	0.027*
3.7 Pearson chi-square	3.7	1.673	0.186	7.107	5.849
3.7 *P*-value	3.7	0.196	0.666	0.029*	0.054
3.8 Pearson chi-square	3.8	2.017	0.000	0.583	1.470
3.8 *P*-value	3.8	0.156	1.000	0.747	0.480
3.9 Pearson chi-square	3.9	0.000	0.000	2.533	1.757
3.9 *P*-value	3.9	1.000	1.000	0.282	0.415
3.10 Pearson chi-square	3.10	0.571	0.063	0.859	0.792
3.10 *P*-value	3.10	0.450	0.801	0.651	0.673

*P-value <0.05.
**P-value <0.01.

Table 5. Data for anatomical variations concerning the IPA, urethral artery considering pelvic halves

	Sex		Side		Profile			Size		
T Number	Male 116	Female 116	Left 116	Right 116	Brach 30	Mesa 180	Dolich 22	Small 62	Med 46	Big 124
5.1	Internal pudendal artery. Figure 5a. Number of cases: 34 = 14.65%									
n	32	2	17	17	4	30	0	8	8	18
%	27.59	1.72	14.66	14.66	13.33	1.67	0.0	12.90	17.39	14.52
5.2	Internal pudendal artery. Figure 5b. Number of cases: 6 = 2.58%									
n	0	6	3	3	0	4	2	1	3	2
%	0.0	5.17	2.57	2.57	0.0	2.22	9.09	1.61	6.52	1.61
5.3	Internal pudendal artery. Figure 5c. Number of cases: 61 = 26.30%									
n	29	32	32	29	7	52	2	14	17	30
%	25	27.59	27.59	25	23.33	28.89	9.09	22.58	36.96	24.19
5.4	Internal pudendal artery. Figure 5d. Number of cases: 4 = 1.72%									
n	3	1	3	1	0	4	0	1	2	1
%	2.57	0.86	2.57	0.86	0.0	2.22	0.0	1.61	4.35	0.81
5.5	Origin of the URa from a *perineal trunk*, branch of the GCA (not illustrated). Number of cases: 7 = 3.02%									
n	0	7	1	6	2	5	0	0	3	4
%	0.0	6.03	0.86	5.17	6.67	2.78	0.0	0.0	6.52	2.22

IPA, internal pudendal artery; *n*, Number of cases; %, percentages in relation to the total specimens.

male and female). Significant values were found for sex (types 3.1, 3.3, 3.4; Table 4; 3.1, 3.3, 3.4 *P*-values), side (types 3.2, 3.4, 3.6; Table 4; 3.2, 3.4, 3.6 *P*-values), profile (types 3.1, 3.3, 3.7; Table 4; 3.1, 3.3, 3.7 *P*-values) and size (types 3.6; Table 4, 3.6 *P*-value).

The urethral, ventral perineal and caudal rectal arteries show a wide range of variations. When the caudal rectal artery is a branch of the ventral perineal artery, the origin of the urethral artery is usually coincident with the origin of the ventral perineal artery (Fig. 6c; Table 5, type 5.3)

Table 6. Chi-squared data in relation to sex, side, profile and size. Data corresponding to Table 5

Degrees of freedom	T number	Sex 1	Side 1	Profile 2	Size 2
5.1 Pearson chi-square	5.1	31.016	0.000	4.402	0.429
5.1 *P*-value	5.1	0.000**	1.000	0.111	0.807
5.2 Pearson chi-square	5.2	6.159	0.000	4.586	3.527
5.2 *P*-value	5.2	0.013*	1.000	0.101	0.171
5.3 Pearson chi-square	5.3	0.200	0.200	4.121	3.422
5.3 *P*-value	5.3	0.655	0.655	0.127	0.181
5.4 Pearson chi-square	5.4	1.018	1.018	1.176	2.490
5.4 *P*-value	5.4	0.313	0.313	0.555	0.288
5.5 Pearson chi-square	5.5	7.218	3.683	2.085	3.878
5.5 *P*-value	5.5	0.007**	0.055	0.353	0.144

*P-value <0.05.
**P-value <0.01.

Table 7. Data of anatomical variations of the ventral perineal and caudal rectal arteries arising from IPA considering pelvic halves

	Sex		Side		Profile			Size		
AVT	Male 116	Female 116	Left 116	Right 116	Brach 30	Mesa 180	Dolich 22	Small 62	Med 46	Big 124
7.1	Figure 7a. Number of cases: 26 = 11.20%									
n	21	5	16	10	4	20	2	4	6	16
%	18.10	4.31	13.79	8.62	13.33	11.11	9.09	6.45	13.04	12.90
7.2	Figure 7b. Number of cases: 5 = 2.15%									
n	4	1	3	2	0	5	0	1	0	4
%	3.45	0.86	2.57	1.72	0.0	2.78	0	1.61	0.0	3.23
7.3	Figure 7c. Number of cases: 1 = 0.43%									
n	0	1	0	1	0	0	1	0	0	1
%	0.0	0.86	0.0	0.86	0.0	0.0	4.55	0.0	0.0	0.81
7.4	Figure 7d. Number of cases: 32 = 13.80%									
n	11	21	15	17	5	24	3	5	8	19
%	9.48	18.10	12.93	14.66	16.66	13.33	13.64	8.06	17.39	15.32
7.5	Figure 7e. Number of cases: 6 = 2.60%									
n	0	6	2	4	1	3	2	0	1	5
%	0.0	5.17	1.72	3.45	3.33	1.67	9.09	0.0	2.17	4.03
7.6	Figure 7f. Number of cases: 38 = 16.38%									
n	12	26	19	19	0	31	7	10	6	22
%	10.34	22.41	16.38	16.38	0.0	17.22	31.82	10.61	13.04	17.74
7.7	Figure 7g. Number of cases: 7 = 3.02%									
n	4	3	2	5	0	7	0	2	2	3
%	3.45	2.57	1.72	4.31	0.0	3.89	0.0	3.26	4.35	2.42
7.8	Figure 7h. Number of cases: 3 = 1.30%									
n	0	3	2	1	2	1	0	0	0	3
%	0.0	2.57	1.72	0.86	6.67	1.11	0.0	0.0	0.0	2.42
7.9	Figure 7i. Number of cases: 2 = 0.86%									
n	0	2	1	1	1	1	0	0	2	0
%	0.0	1.72	0.86	0.86	3.33	1.11	0.0	0.0	4.35	0.0

AVT, anatomical variation type; IPA, internal pudendal artery; *n*, number of cases; %, percentages in relation to the total specimens.

or it is slightly relocated cranially (Fig. 6a; Table 5, type 5.1), while the other three variations could be considered as occasional (Table 5, Fig. 6b, type 5.2; Fig. 6d, type 5.4 and type 5.5, data not illustrated). Only the gender variable showed significant values (types 5.1, 5.2, 5.5; Table 6; 5.1, 5.2, 5.5 *P*-values).

For those cases in which the caudal rectal and the ventral perineal arteries are independent, usually the origin

Table 8. Chi-squared data in relation to sex, side, profile and size. Data corresponding to Table 7

		Sex	Side	Profile	Size
Degrees of freedom	T number	1	1	2	2
7.1 Pearson chi-square	7.1	11.089	1.559	0.237	1.923
7.1 *P*-value	7.1	0.000**	0.212	0.888	0.382
7.2 Pearson chi-square	7.2	1.840	0.204	1.476	1.774
7.2 *P*-value	7.2	0.175	0.651	0.478	0.412
7.3 Pearson chi-square	7.3	1.004	1.004	9.582	0.875
7.3 *P*-value	7.3	0.316	0.316	0.008**	0.646
7.4 Pearson chi-square	7.4	3.625	0.145	0.241	2.456
7.4 *P*-value	7.4	0.057	0.703	0.887	0.293
7.5 Pearson chi-square	7.5	6.159	0.684	4.365	2.706
7.5 *P*-value	7.5	0.013*	0.408	0.113	0.258
7.6 Pearson chi-square	7.6	6.168	0.000	9.798	0.545
7.6 *P*-value	7.6	0.013*	1.000	0.007**	0.762
7.7 Pearson chi-square	7.7	0.147	1.326	2.085	0.439
7.7 *P*-value	7.7	0.701	0.250	0.353	0.803
7.8 Pearson chi-square	7.8	3.039	0.338	7.842	2.647
7.8 *P*-value	7.8	0.081	0.561	0.020*	0.266
7.9 Pearson chi-square	7.9	2.017	0.000	2.533	8.157
7.9 *P*-value	7.9	0.156	1.000	0.282	0.017*

**P*-value <0.05.
***P*-value <0.01.

Table 9. Data for vascular symmetry pattern in both hemipelvises concerning the anatomical variations described in the text

	P/VA (id. Table 1)	MRA (id. Table 2)	URA (id. Table 3)	VPA+CRA (id. Table 4)
n_1	6	96	55	45
$\%_1$	2.59	41.38	23.71	19.40
n_2	20	232	112	120
$\%_2$	30	41.38	49.11	37.5

n_1: number of symmetries present in the total specimens $N = 232$.
n_2: number of the corresponding anatomical variation present in the total specimens $N = 232$.
$\%_1$: global percentages (n_1/N) 100.
$\%_2$: specific percentages (n_1/n_2) 100.

of the ventral perineal is caudal to the origin of the caudal rectal and the urethral arteries (Fig. 7a,b; Table 7, types 7.1, and 7.2). Another interesting variation found in our study is related to the absence of the ventral perineal artery arising from the IPA (Fig. 7d–i; Table 7, types 7.4–7.9); in such cases, the tissue normally supplied by this artery is perfused by the dorsal perineal artery but also and mainly by a 'perineal trunk' coming from the CGA (Avedillo et al., 2014). Such a perineal trunk was present in more than 40% of the analysed samples, and it shows two modalities of branching; in some cases, it sends out a proximal and a distal branch, which are the dorsal and ventral perineal arteries respectively, and in other cases, it gives off a variable number of small vessels. The relationship between the ventral perineal, the dorsal perineal arteries and the perineal trunk is an interesting and attractive topic that will be addressed separately later, together with a clinical orientation (manuscript in preparation). Occasionally, the caudal rectal artery is also absent from the terminal part of the IPA (Fig. 7h,i; Table 7, types 7.8 and 7.9), the same was also observed for the urethral artery (Fig. 7i; Table 7, types 7.9). Significant values were found for sex (types 7.1, 7.5, 7.6; Table 8; 7.1, 7.5, 7.6 *P*-values), profile (types 7.3, 7.6, 7.8; Table 8; 7.3, 7.6, 7.8 *P*-values) and size (types 7.9; Table 8, 7.9 *P*-value).

An equal vascular pattern in both hemipelvises, that is symmetry between the right and left sides, is an interesting issue concerning anatomical variations. It is worth noting that the specific percentages of symmetry observed in the present study lie between 30–50% (Table 9).

Apparently, no anatomical variations found have a logical *a priori* explanation. In general, the reasons for the presence of any AVBVS should be sought in the evolution of the vascular system during development, and in the changes that occur from embryo to foetus to neonate

(Russe and Sinowatz, 1994; Sadler, 2012). The different arterial patterns originated during embryogenesis by a selection of channels form an initially homogenous capillary network. While some vascular channels enlarge, others retract and disappear, which results in establishing the final arterial pattern (Arey, 1963). Therefore, it is likely that AVBVS will be more frequent in those anatomical regions in which the changes in development are more significant.

Similar to human anatomy, in which the internal iliac artery may show an important number of AVBVS within any human ethnic group, varying between eight according to Adachi (1928) and nineteen in the relatively recent update by Yamaki et al. (1998), it is reasonable to think that in dogs, the presence of AVBVS related to IPA is based on breed diversity. The observed anatomical variations are related to the major branches of the internal pudendal artery which are the prostatic/vaginal, urethral and ventral perineal arteries, as well as to some of their branches (i.e. the middle and caudal rectal arteries). A proposal to classify these types of modifications is presented in the present study.

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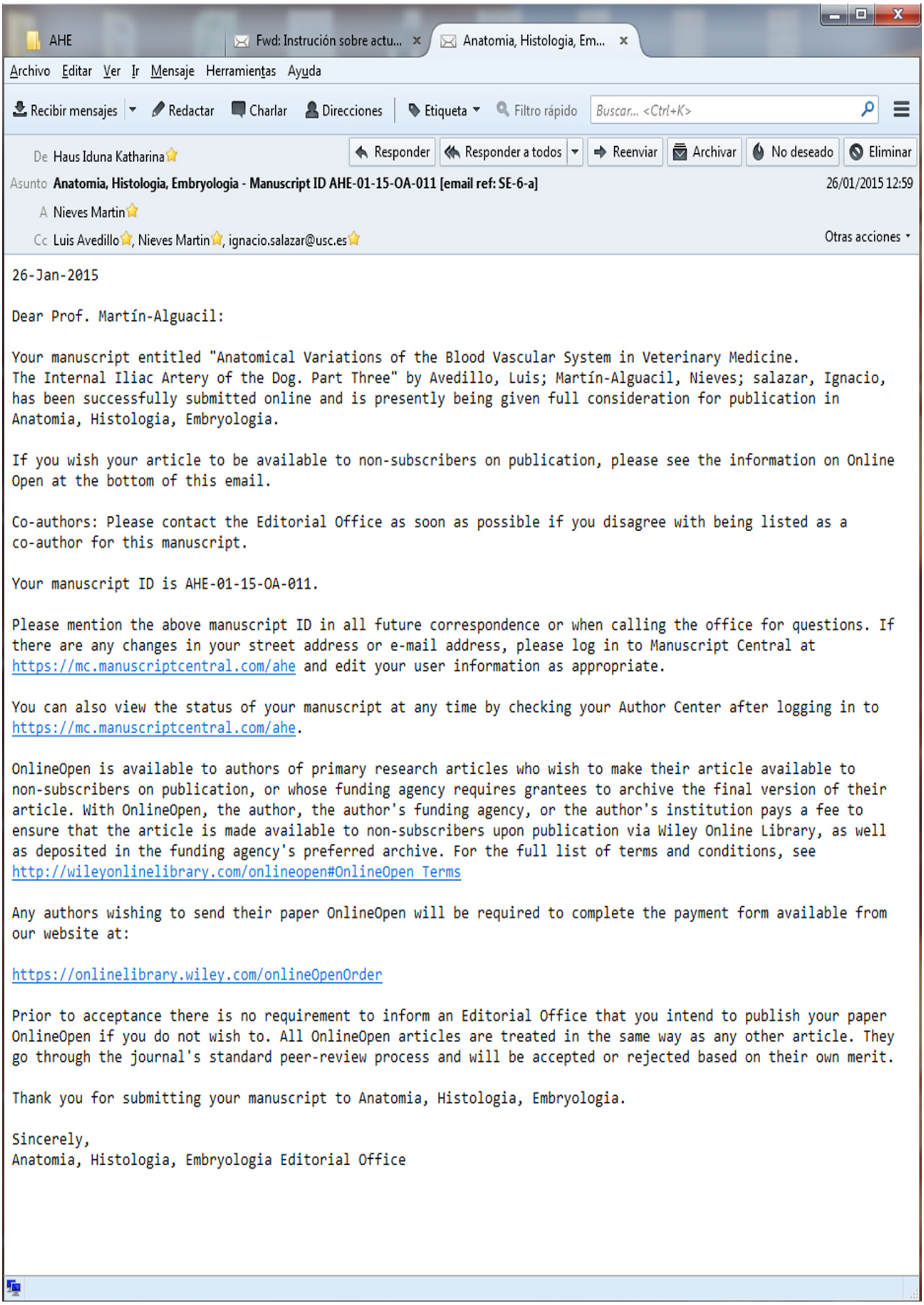
4. MANUSCRITOS EN PROCESO DE REVISIÓN

Los resultados obtenidos en el trabajo desarrollado durante el periodo dedicado a la elaboración de la tesis doctoral han dado lugar además a la elaboración de otros dos manuscritos. Aun a sabiendas que ese tipo de documentos en proceso de revisión no tienen valor real, se incluyen a continuación debido a que son una continuación lógica de los estudios ya publicados, y complementan a los mismos. En el primero de ellos se abordan las variaciones relativas a la arteria umbilical, la tercera rama de la arteria ilíaca interna, y se ha remitido a la misma revista en donde están publicadas las partes una y dos. Es de suponer que en breve se tendrán noticias de la editorial. El segundo de los manuscitos recoge la organización arterial perineal, la cual muestra unas variaciones considerables que se entiende son interesantes desde el punto de vista clínico. En este caso el manuscristo se ha remitido a la revista Veterinary Surgery también se está a la espera de la contestación.

4.1. **Anatomical variations of the blood vascular system, in veterinary medicine. The internal iliac artery of the dog. Part three.**



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26-Jan-2015

Dear Prof. Martín-Alguacil:

Your manuscript entitled "Anatomical Variations of the Blood Vascular System in Veterinary Medicine. The Internal Iliac Artery of the Dog. Part Three" by Avedillo, Luis; Martín-Alguacil, Nieves; salazar, Ignacio, has been successfully submitted online and is presently being given full consideration for publication in Anatomia, Histologia, Embryologia.

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Anatomical Variations of the Blood Vascular System in Veterinary Medicine. The Internal Iliac Artery of the Dog. Part Three

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With 7 figures and 3 tables

Summary

The aim of this study was to analyze and describe the variability of the umbilical artery. Two hundred and thirty-two pelvic halves from 116 adult dogs were examined. To study the permeability of the umbilical artery ten adult dogs, nine newborns and thirteen foetuses between 35 and 50 days of gestation were also used. In relation to the origin of the umbilical artery six anatomical variations were found. From which five involved a cranial (n=4) or caudal (n=1) relocation of its origin, and in one case (n=1) the umbilical artery arose from the median sacral artery. In eight cases the umbilical artery gave off the prostatic (n=1) or vaginal (n=7) arteries. The permeability of the umbilical artery was the most significant anatomical variation: permeability was detected in 45% (106 of 232 pelvic halves) of all cases, from which 36 were males and 70 females. Interestingly, an equal vascular permeability in both hemi-pelvises was found for 82% of the dogs, thus additional data related to such feature of the umbilical artery was also recorded. In accordance with the statistical study the main anatomical variations described showed significant values for gender, side of the body, size and profile variables.

Introduction

The anatomical variations of the blood vascular system (AVBVS) have been previously described in dog with special reference to the caudal gluteal (CGA) (Avedillo et al., 2014) and internal pudendal (IPA) (Avedillo et al., 2015) arteries. In most domestic animals the IIA has three main branches: the CGA and the IPA parietal and visceral branches respectively, and the umbilical artery (UA). The UA plays a very important role in blood circulation before and after birth. During foetal circulation UA carries the blood from the aorta to the placenta for renewal. At birth when the umbilical cord is disrupted the lumen of the UA becomes obliterated distally due to the smooth cells contraction within the wall of the artery. It will evolve showing a partial or complete degeneration, that in any case will contribute to form the round ligament of the urinary bladder and it may lead to supply part of the urinary bladder through the cranial vesical artery (Noden and de Lahunta, 1985; Rüsse and Sinovatz, 1994; Mc Geady et al., 2006).

The peculiar features of the UA during the foetal period make this artery an interesting subject of study in both human and veterinary medicine (Di Salvo et al., 2006; Blanco et al., 2008; Miranda and Domingues, 2010; Blanco et al., 2011; Polchow et al., 2012; Roffino et al., 2012; Bai et al., 2013). Nevertheless in adult specimens the interest of UA is focused in the anatomy, i.e. size, origin, course, branching, ending, and topography of the vessel itself. In human medicine AVBVS have been studied in detail. Work by Adachi (1928) is commonly considered the universal reference model for vascular anatomy. Although he did not consider the UA in his first classification, it was included after several decades when the Adachi classification was revised (Yamaki et al., 1998).

The study of the AVBVS in veterinary medicine is quite complex due to the variety of domestic mammals (cows, sheep, goats, pigs, horses, cats and dogs), and the variety of breeds in each species. Contemporary anatomical text books are more focused on establishing differences between species rather than in the anatomical variations issue (Getty, 1975; Schummer et al., 1981; Barone, 1996). Such differences were suitable organized, in the *Nomina Anatomica Veterinaria* (NAV, edited by the International Committee on Veterinary Gross Anatomical Nomenclature, 2012), and carefully described and illustrated (Constantinescu and Schaller, 2011).

The purpose of our research is to complete the study of the anatomical variations in the internal iliac artery (IIA) of the dog. This study analyses those variations in the umbilical artery (UA).

Material and methods

The proceeding used to study AVBVS of the UA is described in IIA variations Part 1 (Avedillo et al., 2014). Ten adult, 9 newborns, and thirteen foetuses (35-50 days of gestation) dogs were additionally used in this study. All the specimens used came from dissecting and post-mortem rooms. All animals were legally procured in accordance with the regulations and laws of the European Union (86/609/EEC) and Spain (RD 223/1998) for the care, use, and housing of animals in research. The study was approved by the Universidad Complutense de Madrid Bioethics Committee.

Eight adult dogs were injected with coloured natural latex following the same procedure described in IIA variations Part 1, and permeability was observed macroscopically and results were evaluated and recorded. The UA was isolated and excised from 2 adults, 8 newborns, and 13 foetuses dogs. These arteries were fixed in 10% formalin for 4-6 days. Each vessel was then divided at different levels and all pieces were kept in 10% formalin for 48 hours. Each piece was then rinsed with distilled water, dehydrated, and paraffin embedded. 8□m thick transverse sections were obtained, mounted and stained with hematoxylin-eosin or orcein. Samples of the IIA and the prostatic artery were also processed for the histological study.

The chi-squared test for independence or homogeneity was used to analyse differences in gender, side of the body, profile and size, and the results were considered statistically significant when $p \leq 0.05$.

Results

The findings described were observed during the entire phase of preparation and the anatomical specimens, and final results are shown in Fig.1. The model chosen to make the pertinent comparison is represented in Fig. 2.

UA arises from the IIA at the level of the seven lumbar vertebra, and this landmark is fairly constant. In one specimen the UA arises directly from the median sacral artery, and in five specimens it shows a cranial or caudal relocation in its origin (Fig. 3). Three anatomical variations were identified for the UA branching: 1) in one specimen (case 44, left side) the UA gave off the prostatic artery; 2) in seven specimens (cases: 28 right side; 67 both sides; 68 both sides; 90 left side; 114 right side) the UA gave off the vaginal artery (Fig. 3); 3) in one-hundred-and-six specimens, 36 males and 70 females, the lumen of the vessels was filled with latex, and in those cases the UA gave rise to the cranial vesical arteries. An equal vascular pattern in both hemi-pelvises was observed in 82.08% of cases (77.8% males, and 84.3% females). UA permeability was clearly demonstrated macroscopically in 8 fresh specimens (Fig. 4), and the characteristics of its arterial wall were shown histologically. In foetuses older than 35 days of gestation and in newborns, the UA is similar at the level of the urinary bladder (Fig. 5A and B) and quite different at the level of the umbilical opening (Fig. 5C and D). When the IIA and prostatic artery wall was compared with the UA wall from adults (Fig. 6 A and B), a change in its appearance was observed in the surrounding tissue of the tunica adventitia and the change went from proximal to distal (Figs. 6 C, D, E, and 7). Data and statistical analyses are recorded in Tables 1, 2 and 3.

Discussion

The anatomical variations of the CGA (Avedillo et al., 2014) and IPA (Avedillo et al., 2015) in the dog were accurate studied and classified. In the present study we will discuss the anatomical variations of the UA following the same established criteria. It is commonly considered by human anatomists that the UA in adults has two differentiated parts: a patent and an occluded one. The patent part of the UA gives off the vessels to the vas deferens, ureteric branches and superior vesicle arteries; whereas the occluded and most anterior part of the UA it becomes obliterated after birth (International Anatomical Nomenclature Committee, 1983; Federative Committee on Anatomical Terminology, 1998; Feneis and Dauber, 2000). In the referred model they described three possible anatomical variations:1) both the right and left arteries merged into a single trunk; 2) a total permeability in the artery (see below); and 3) supernumerary branches may be present (Dubreuil-Chambardel, 1925; Testut and Latarjet, 1979; Lippert and Pabst, 1985). In addition, anatomical variations referred to the origin of the UA are numerous. UA either arises from the main stem of the IIA, or from its main branches: the superior gluteal, inferior gluteal, or internal pudendal arteries (Yamaki et al., 1998). The fact that AVBVS in human are studied in great detail makes these information very valuable.

It shows the high presence of anatomical variations of the UA in adults, an artery which is no longer considered as important vessel after birth (Lippert and Pabst, 1985).

In the domestic mammals four different models have been proposed for the general organization and distribution of the UA, which include *Carnivora* (dog and cat), *Sus* (pig), *Ruminantia* (cow, sheep and goat) and *Equus* (horse) (Constantinescu and Schaller, 2011; International Committee on Veterinary Gross Anatomical Nomenclature, 2012). The branching model for the UA is exactly the same for human and horse; that is the UA arises from the IPA. Some similarities are found between the human and pig models; the UA gives rises to the uterine artery and its corresponding ureteric branches. The model for the cow is close to that described for the pig; ureteric branches are absent in males and have an independent origin in females. In *Carnivora* ramifications of the UA are restricted to the cranial vesical artery, although this vessel is considered constant in cats it is considered a common anatomical variation in dogs (Constantinescu and Schaller, 2011; International Committee on Veterinary Gross Anatomical Nomenclature, 2012). Even though this anatomical variation is not specified or quantified in theveterinary anatomical textbooks, some authors believe that the cranial vesical artery is usually absent in the dog (Schummer et al., 1981) while some others consider that the cranial vesical artery is small and slender and is present in about half of the specimens (Barone, 1996; Evans and de Lahunta, 2013).

Regarding the origin of the UA we were not able to find any case in which the artery arose from the terminal portion of the aorta as it was suggested previously (Getty, 1975; Evans and de Lahunta, 2013), or caudally to the promontory (Nitschke and Preuss, 1971), we rather have observed a constant place of origin for the UA at the level of the seventh lumbar vertebra, with a slightly cranial or caudal relocation. One anatomical variation was only observed in the origin of the UA; which is the artery arising from the sacral median artery, and it can be considered the exception that proves the rule. In reference to the UA branching our results showed that in a low percentage –3.5% of the studies cases– the UA gives off the prostatic and/or vaginal arteries, with a significant value for differences in sex and profile in agreement to the chi-squared test for independence.

The more controversial issue related to the branching of the UA in dogs concerns to the existence of the cranial vesical artery, and to its permeability. Permeability is considered as the ability of molecules to pass through blood vessels and reach tissue through a thin layer of their wall or endothelium (Banks, 1981; Komarova and Malik, 2010), but the term permeability may be used to indicate that the UA has enough lumen to carry blood and to supply the urinary bladder. Our results showed that in 46% of the studied specimens the UA is permeable (31% in males and 60% in females), with significant values for differences in gender and size. An equal vascular pattern for permeability was observed in 81.1% of the studied cases in both hemi-pelvises. When the UA is permeable a double question arises: 1) does the cranial vesical artery of dogs supply the same territory of the urinary bladder than does the cranial vesical artery in other domestic mammals? and 2) what happens when the cranial vesical artery is absent? A logical answer could be given by the fact that in dogs the caudal vesical artery is more developed, and this vessel could be acting as a “compensatory system” to the cranial branch; comparative illustrations of the arterial tree of the pelvic viscera highlight the evidence (Schummer et al., 1981; Barone, 1996). The significative differences showed in the histological study among adults, newborns and faetal specimens are in concordance with the permeability location (proximal or distally) and the role that plays the wall in the UA.

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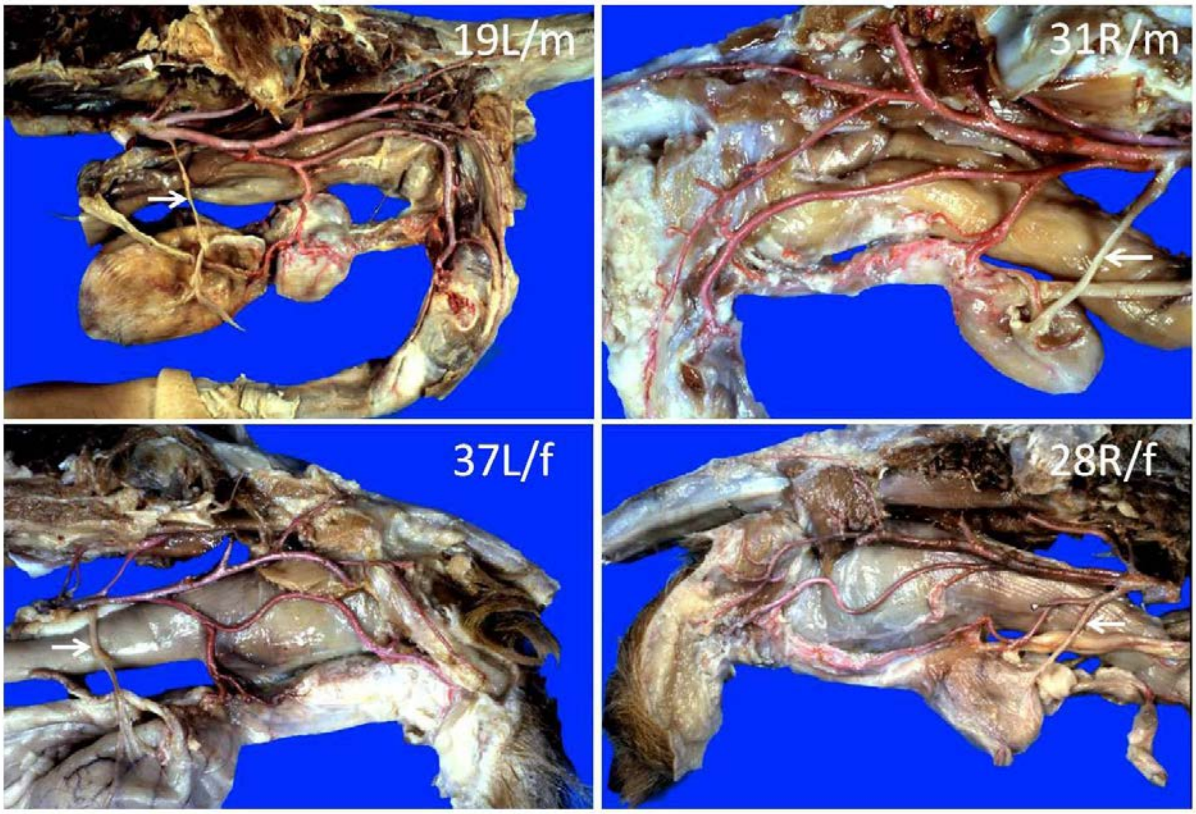


Fig. 1. Macrophotographs of four hemi-pelvises, left (L) and right (R) sides, male (m) and female (f), showing the final results of the anatomical preparations.

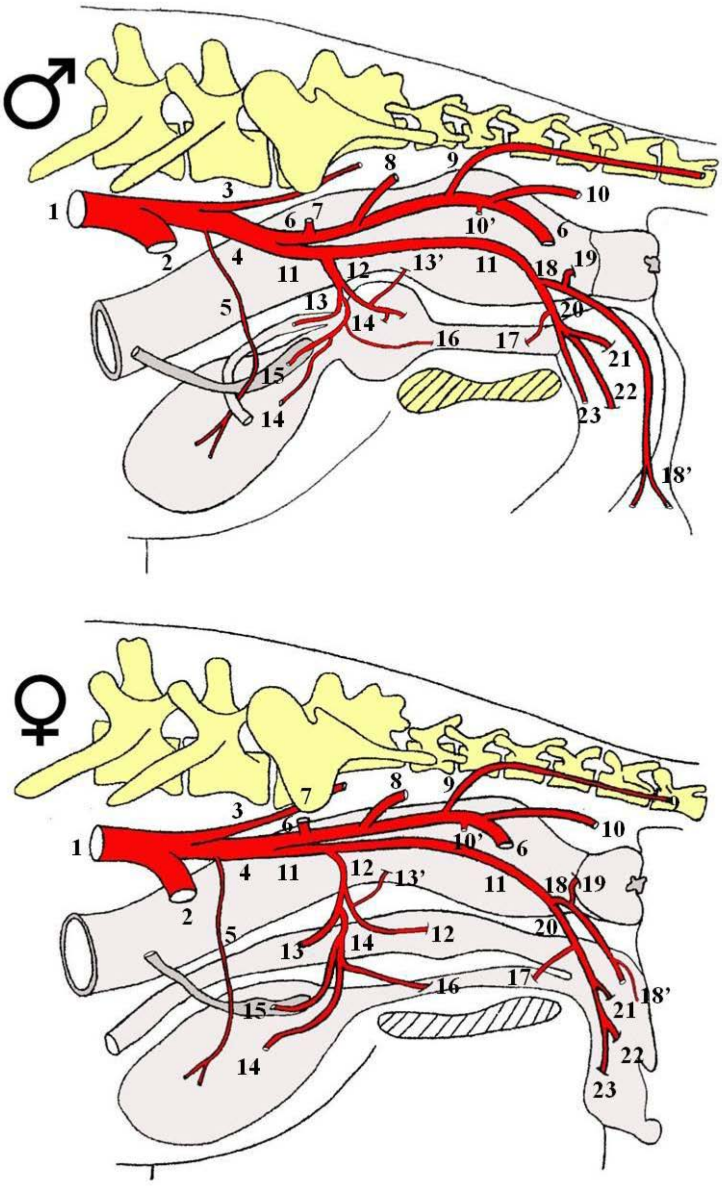


Fig. 2. Presumptive anatomical model used as reference for the general distribution and major branches of the internal iliac artery in male and female dog. 1 Abdominal aorta; 2 external iliac; 3 median sacral; 4 internal iliac; 5 umbilical; 6 caudal gluteal; 7 iliolumbar; 8 cranial gluteal; 9 lateral caudal; 10 dorsal perineal; 10’ satellite of the ischiatic nerve; 11 internal pudendal; 12 prostatic/vaginal; 13 ductus deferens/uterine; 13’ middle rectal; 14 caudal vesical; 15 ureteral branch; 16 urethral branch; 17 urethral; 18 ventral perineal; 18’ dorsal scrotal branch/dorsal labial branch; 19 caudal rectal; 20 artery of the penis/clitoris; 21 bulb of the penis/vestibular bulb; 22 deep artery of the penis/clitoris; 23 dorsal artery of the penis/clitoris.

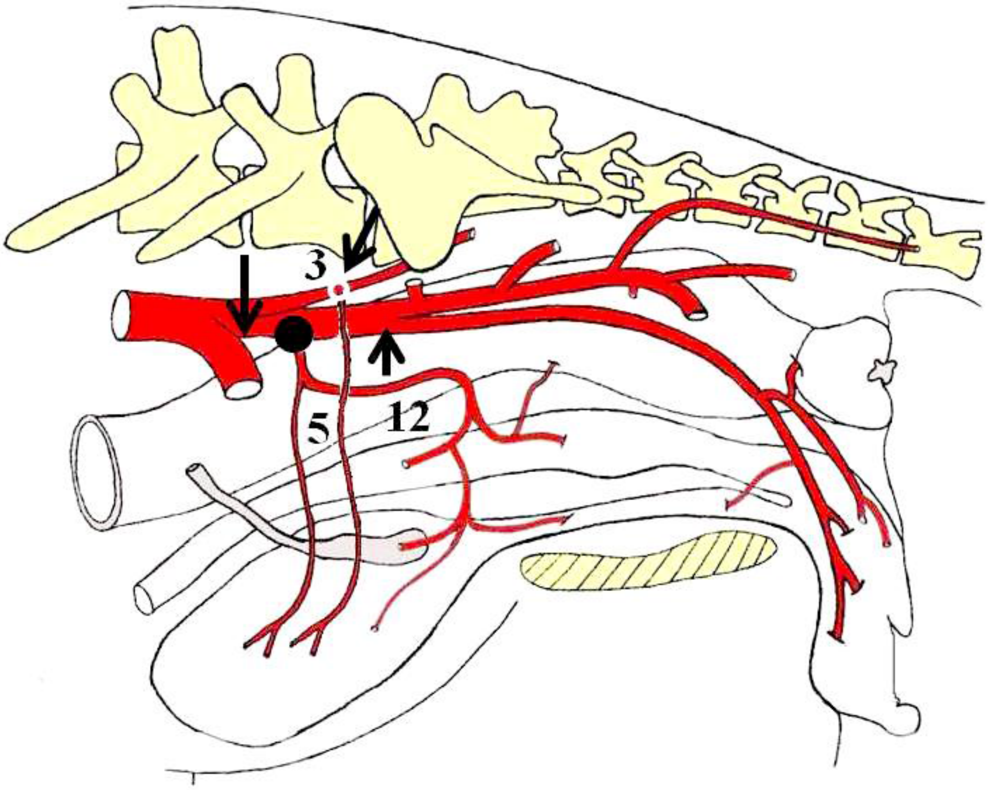


Fig. 3. Anatomical variation in the origin of the umbilical artery (5) with regard to its usual topography (asterisk): cranial and caudal relocation (arrows) and on the median sacral artery (3, arrowhead). In some specimens the umbilical artery gives off the vaginal (12) or prostatic arteries. Numbers correspond to the legend of Fig. 2.

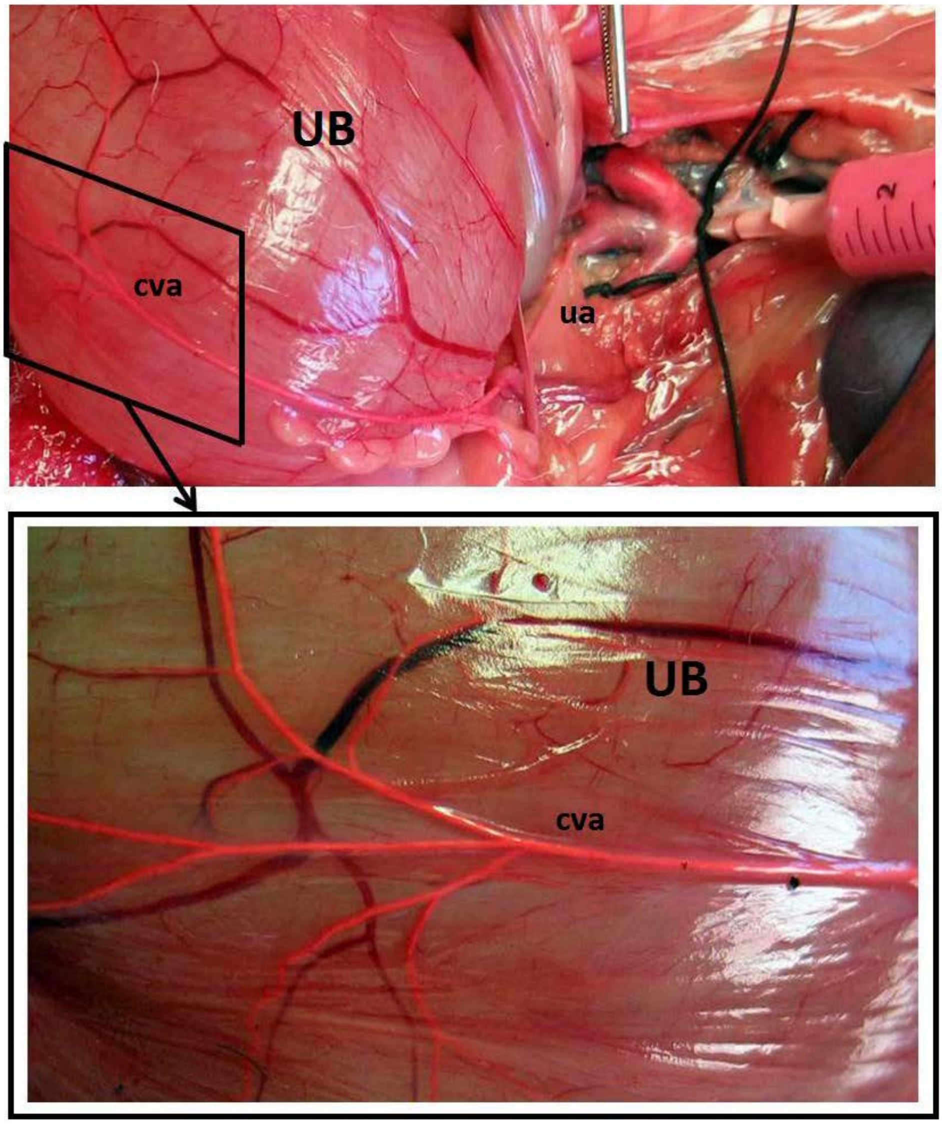


Fig. 4 Macrophotographs showing (A) the permeability of the umbilical artery (ua) after injection with colored latex, (B) magnification showing the course of the cranial vesical artery (cva) in the urinary bladder (UB).

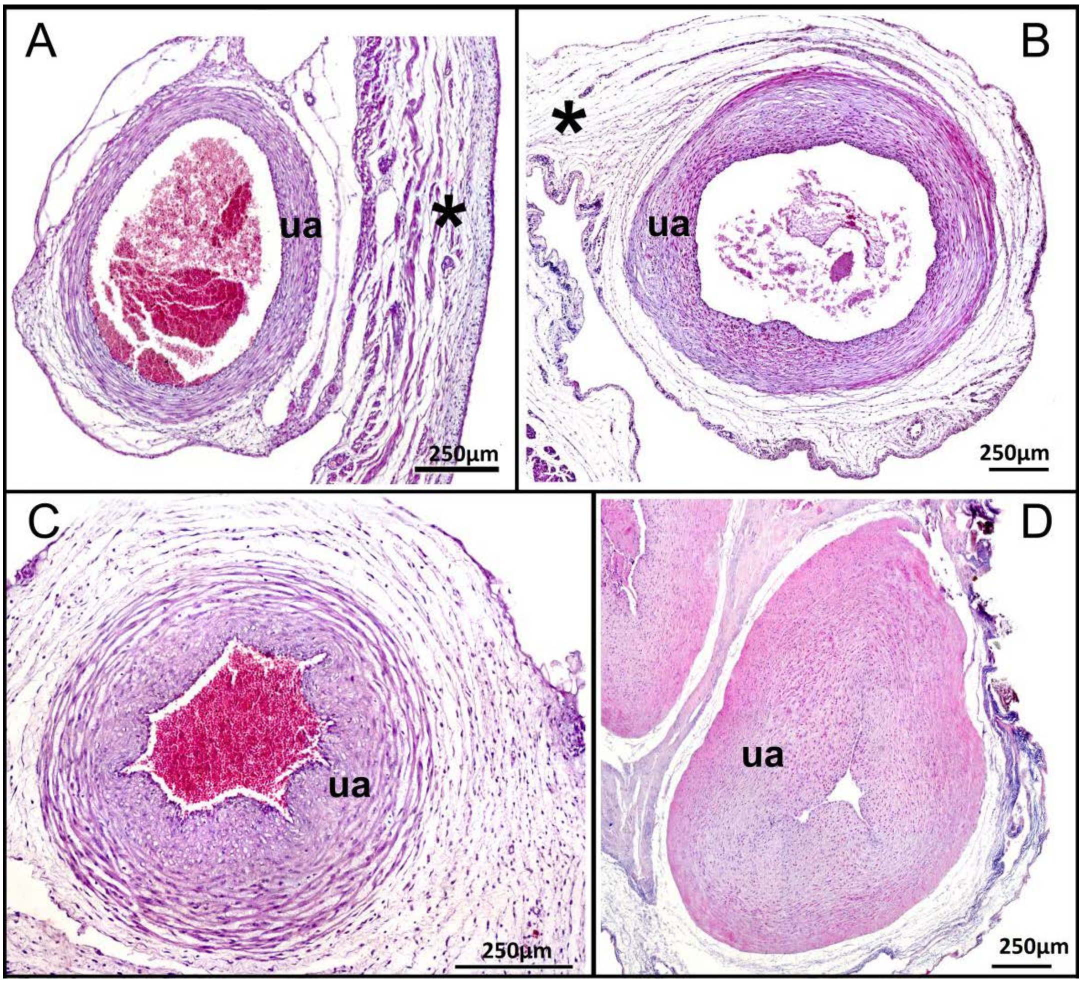


Fig. 5 Transverse sections of the umbilical artery (ua) stained with Hematoxilin & Eosin. At the middle level where it is associated with the urinary bladder (asterisk): (A) in 40 days of gestation dog foetus, and (B) in newborn dog. At the umbilical opening: (C) in 40 days of gestation dog foetus, and (D) in a newborn dog, note that the ua is almost completely collapsed.

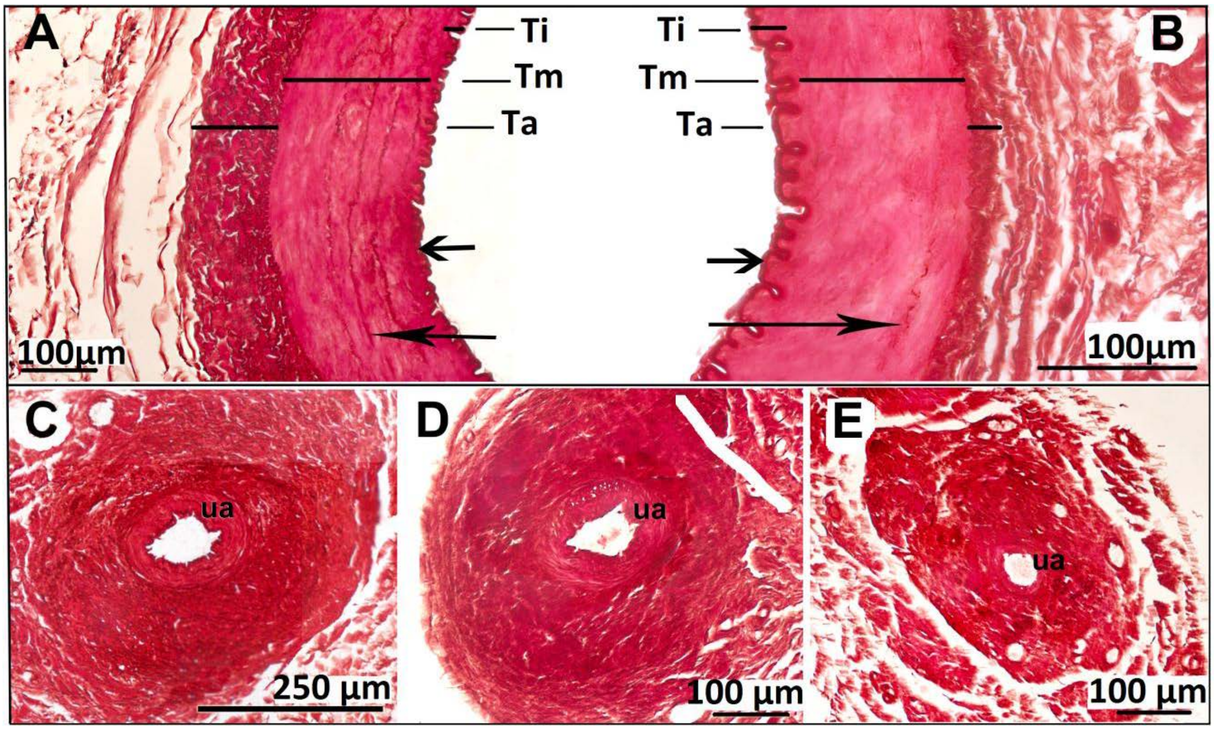


Fig. 6 Transverse section of the internal iliac (A) and prostatic (B) arteries from an adult dog showing the mural organization and the elastic tissue (arrows); (Ta) Tunica adventitia; (Ti) Tunica intima; (Tm) Tunica media. Transverse section of the umbilical artery (ua) at three different levels: (C) proximal, (D) middle, and (E) distal (levels were selected according to Fig. 7). Sections stained with Orcein.

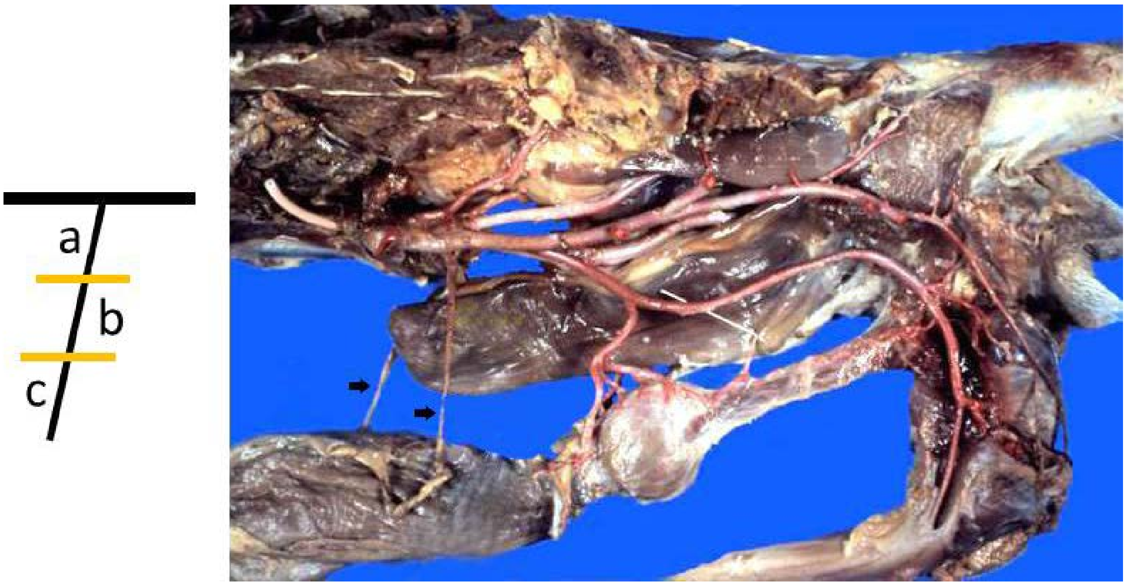


Fig. 7 Macrophotograph of the left side hemi-pelvis of a male dog, showing the final results of the anatomical preparation, note left and right umbilical arteries (arrows).

Table 1
Data for anatomical variations concerning the UA considering pelvic halves.

	SEX		SIDE		PROFILE			SIZE		
	male	**female**	**left**	**right**	**brach**	**mesa**	**dolich**	**small**	**med**	**big**
Number	**116**	**116**	**116**	**116**	**30**	**180**	**22**	**62**	**46**	**124**
1.1	**Umbilical artery gives off the prostatic/vaginal arteries.** Number of cases: 8 = 3,45%									
n	1	7	4	4	0	8	0	4	0	4
%	0,86	6,03	3,45	3,45	-	4,44	-	6,45	-	3,23
1.2	**Umbilical artery arises from the median sacral artery.** Number of cases: 1 = 0,43%									
n	1	0	0	1	0	1	0	0	0	1
%	0,86	-	-	0,86	-	0,56	-	-	-	0,81
1.3	**Traditional anatomical model.** Number of cases: 223 = 96,12%									
n	114	109	112	111	30	171	22	58	46	119
%	98,28	93,97	96,55	95,69	100	95,00	100	93,55	100	95,97

Table 2

Data for permeability of the UA considering pelvic halves.

	SEX		SIDE		PROFILE			SIZE		
	male	**female**	**left**	**right**	**brach**	**mesa**	**dolich**	**small**	**med**	**big**
Number	**116**	**116**	**116**	**116**	**30**	**180**	**22**	**62**	**46**	**124**
2	**Permeability.** Number of cases: 106 = 45,69%									
n	36	70	54	52	12	80	14	43	13	50
%	31,03	60,34	46,55	44,83	40,00	44,44	63,64	69,35	28,26	40,32

Table 3

Results of Chi-Square Test for Independence or Homogeneity

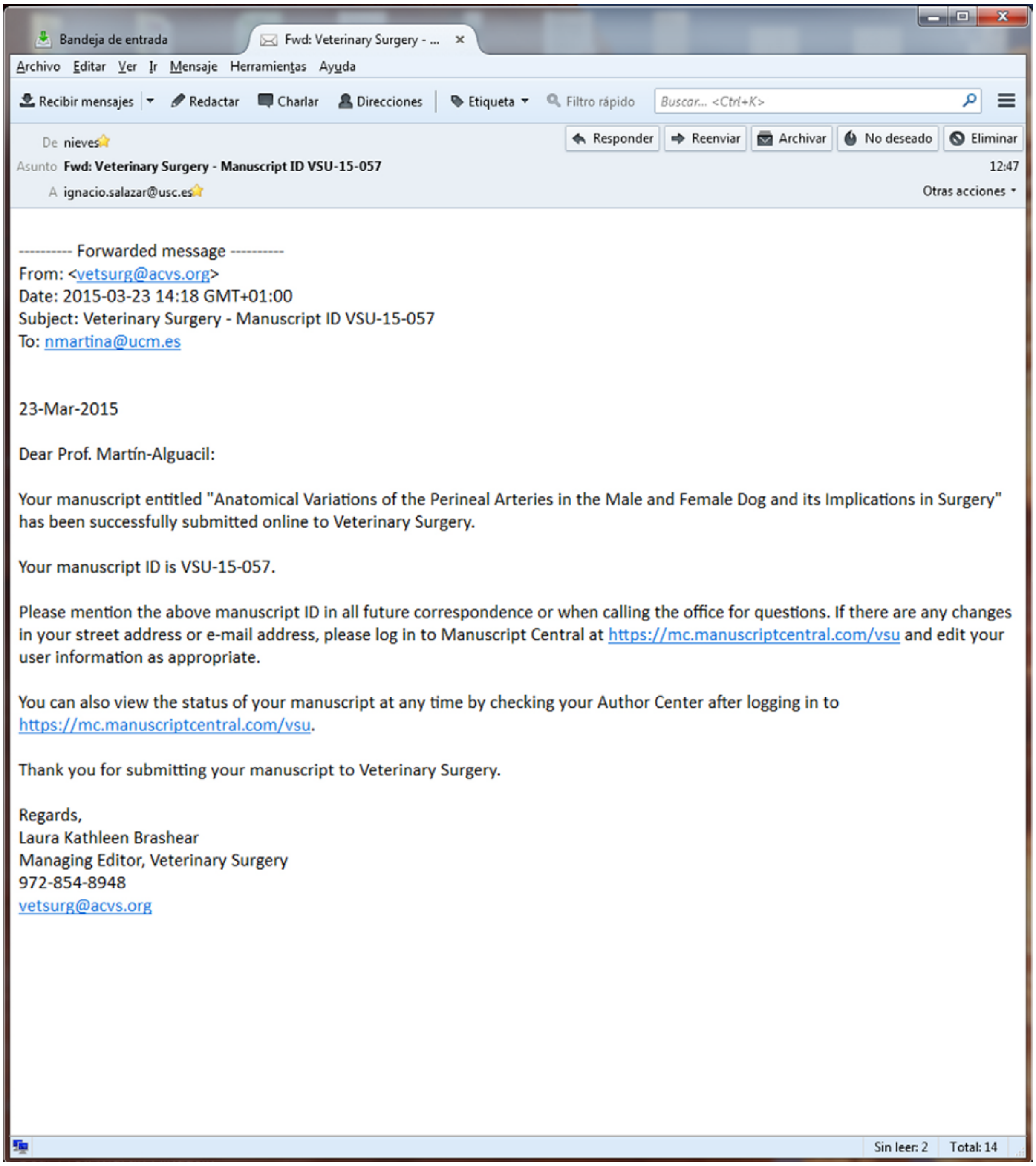
1.1, 1.2, 1.3: table 1 data

2: table 2 data

	SEX	**SIDE**	**PROFILE**	**SIZE**
Degrees of freedom	1	1	2	2
1.1 Pearson chi Square	4,661	0,000	2,394	3,341
1.1 P-value	0,031*	1,000	0,030*	0,188
1.2 Pearson chi Square	1,004	1,004	0,290	0,875
1.2 P-value	0,316	0,316	0,865	0,646
1.3 Pearson chi Square	2,890	0,116	2,705	2,964
1.3 P-value	0,089	0,734	0,259	0,227
2. Pearson chi Square	20,080	0,069	3,359	25,078
2. P-value	0,000**	0,792	0,186	0,000**

*: P-value < 0,05 **: P-value < 0,01

4.2. **Anatomical variations of the perineal arteries in the male and female dogs and its implications in surgery.**



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Running head: Perineal arteries variations.

Anatomical Variations of the Perineal Arteries in the Male and Female Dog and its Implications in Surgery

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ABSTRACT

Objective: To improve the understanding of the vascularization of the perineal region, providing detail information on the perineal arteries and their variability in the male and female dog.

Study designed: Cadaveric anatomical study.

Animals or Sample Population: 232 pelvic halves from 116 adult dogs for dissection.

Methods: Using traditional anatomical technique, the specimens studied were prepared and injected with coloured natural latex. The chi-squared test was used to analyse differences in sex, side of the body, profile and size, and the results were considered statistically significant when $p \leq 0.05$.

Results: The presumptive model was observed in 46% of the specimens. A dorsal perineal artery “long type” was found 13% of the dogs. A perineal trunk was present in 41% of the dogs, from which 24% was observed in males and 58% in females.

Conclusions: Our findings contribute to the understanding of the vascular variations of the perineal arteries and may be highly relevant to clinical practice and especially beneficial for veterinary surgeons when approaching the perineal region in the male and female dog.

INTRODUCTION

Anatomical variations of the blood vascular system (AVBVS) are considered as modification of the vessels when compared to an established pattern.[1] Although variations are also described as anomalies, relationships between AVBVS and congenital malformations do not exist, which implies variations have no effect on the function of an organ under normal circumstances.[2,3] That is the case when consider AVBVS of perineal arteries in the dog which are asymptomatic and occasionally be detected during routine cadaveric dissections. Nevertheless these anomalous vessels may be at risk in perineal reconstruction that requires dissection or suturing along the pelvic wall, pelvic diaphragm and perineal region.

The use of classical anatomy textbooks as reference approaching the perineal region is well documented in veterinary surgery textbooks,[4-6] as well as in publications in veterinary surgery.[7-14] In these texts it is commonly accepted that the dorsal perineal artery arises from the caudal gluteal artery within the ischiorectal fossa (near the origin of the lateral caudal artery) and passes caudally, where it supplies blood to the skin and adipose tissue of the perineal region. Whereas ventral perineal artery arises from the internal pudendal artery and it supplies the ventral part of the perineal region.

To evaluate the presumptive AVBVS of the internal iliac artery (IIA) Avedillo et al.[1,15] established a model of the general organization and distribution of the canine IIA using the guidelines established by the NominaAnatomicaVeterinaria.[16] The model was logically structured to be easily followed by viewing the “official illustration” made by Paul Simoens.[17] When compared that model to their findings they described several anatomical variations in the caudal gluteal,[1] and the internal pudendal[15] arteries and its branches.

There are many surgical procedures where the perineal arteries integrity can be compromised in surgery peripheral to the anus, anal sacculectomy, or perianal mass excisions,[18,19] perianal fistula,[20,21] perineal hernia repair,[19] vulvar fold excision and partial vulvar resection,[18,22] in perineal skin defects as result of traumatic injuries,[13,14,23] even when solving some other process like urinary incontinence.[12]

Successful aesthetic and functional perineal reconstruction requires adequate skin cover and well vascularised tissue. The caudal superficial epigastric, lateral caudal, and deep circumflex iliac axial pattern flaps are routinely used for cutaneous reconstruction of the perineum.[7-9,18,23-27] Scrotal flap[10,13] as well as dorsal vulvar skin[14] have been also successfully used as a transposition flap for closure perineal skin defects in the male and female dogs. For axial pattern flaps, it is critical to include and preserve the direct cutaneous vessel. Although necrosis of the entire flap is uncommon, necrosis usually involves the tip and is called distal tip necrosis. The most common cause of flap necrosis is inadequate blood perfusion.[28] Blood supply to the flap is limited by the extent of direct cutaneous vasculature; for this reason, it is important to follow adequate anatomic guidelines for axial pattern flap development established for dogs to ensure flap survival and minimize surgical complications.

The purpose of this research is to discuss the anatomical findings of the various vascular anomalies related to the perineal arteries, as well as the morphological and clinical significance of these vascular anomalies for future references.

MATERIALS AND METHODS

The 116 dogs used in this study came from dissecting and post-mortem rooms. All animals were legally procured in accordance with the regulations and laws of the European Union (86/609/EEC) and Spain (RD 223/1998) for the care, use and housing of animals in research. The study was approved by the Complutense University of Madrid Bioethics Committee. Due to the high number of cross-breeds, dogs were grouped according to their head shapes or weight into three categories.

Using traditional anatomical techniques, the specimens studied were prepared and injected with coloured natural latex. The IIA and its major branches were exposed, and photographs and drawings were made systematically. During the entire process of dissection, special attention was paid to the origin and variations of the perineal arteries, and the data were recorded with the highest possible accuracy. The traditional anatomical model considers the IIA gives off the umbilical artery, the internal pudendal artery (IPA) and caudal gluteal artery (CGA), and the IPA branches are the prostatic/vaginal, ventral perineal arteries, and the artery of the penis/clitoris. And the CGA branches are the iliolumbar, cranial gluteal, lateral caudal, satellite of the ischiatic nerve and dorsal perineal arteries. The variations described are schematically represented according to the conventional system used in human anatomy (Fig 1).

The chi-squared test for independence or homogeneity was used to analyse differences in sex, side of the body, profile and size, and the results were considered statistically significant when $p \leq 0.05$.

RESULTS

A total of 232 hemi-pelvises belonging to 116 adult dogs, 58 males and 58 females were examined. The number of dogs in each category was as follows: (1) head shape: 15 brachycephalic, 90 mesaticephalic and 11 dolichocephalic dogs, and (2) weight: 31 small (< 6kg), 23 medium (7-20kg) and 62 big (> 20kg) dogs. The findings described were observed during the entire phase of preparation of the anatomical specimens, and final results are shown in Fig 2, 4, and 5. The model chosen to make the pertinent comparisons is represented in Fig 3A.

In the first anatomical variation the dorsal perineal artery is considerably longer than usual and with a larger diameter of the vessel; that is, the length of the ventral perineal artery is reduced as well as the vessel diameter (Fig 2C and D, and 3B, Table 1). A 0.4% of symmetry was detected between right and left side (Table 3).

An additional vessel was present in the second variation consider herein. The so called “perineal trunk” where the dorsal perineal artery does not take origin directly from the CGA but from common trunk (Fig 2E and F, and 3C). Perineal trunk was present in 95 of the 232 hemi-pelvises studied (Table 1). The perineal trunk constantly courses together with the superficial perineal nerve and supplies the skin, subcutaneous and adipose tissues of the perineal region (Fig 4).The presence of the perineal trunk is always related to the absence of the ventral perineal artery from the IPA; in such cases the tissue supplied by it is compensated by the dorsal perineal artery but also and mainly by the perineal trunk *per se* coming from the CGA. The perineal trunk shows two modalities of branching; in 76% of the cases it sends out a proximal and a distal branch, the dorsal and ventral perineal arteries respectively, and in 24% of the cases it gives off a no defined number of small vessels. A 5.2 % of symmetry was detected between right and left side (Table 3).

Two more isolated cases, in female (right side), show particular anatomical variations Fig 5. In one of them the ventral perineal artery arises from CGA distally to the origin of the cranial gluteal artery. In this case the ventral perineal artery arises at the level of the sacrocaudal joint courses caudoventrally giving off the caudal rectal artery and supplies the ventral part of the perine. The caudal rectal artery gives off the urethral artery (Fig 5A), while in the other one, at the level of the II caudal vertebra the IPA gives off a common trunk for the lateral caudal artery and a perineal trunk that gives off dorsal perineal and ventral perineal arteries (Fig 5B).

DISCUSSION

When planning any surgical proceeding a deep knowledge of the anatomical landmarks is highly recommended. This is especially helpful when dealing with perineal defects that require surgical reconstruction. The surgeon must be aware of the considerably high incidence of AVBVS within the pelvic cavity and the perineal region in the dog. A great variety of AVBVS were described for the IIA of the male and female dog.[1,15] A first study describing anatomical variations of the CGA,[1] and second one for the IPA variations.[15] Despite the variations observed in the origin of the dorsal perineal and ventral perineal arteries described previously, we are going to focus our discussion in those two vascular variation of perineal arteries with the highest incidence and clinical relevance.

Perineal arteries are those vessels that irrigate the skin, and the subcutaneous connective tissue of the perineal region. The dorsal part is supplied by the dorsal perineal artery whereas ventral perineal artery irrigates its ventral part. These arteries course together with the superficial perineal nerve. The dorsal perineal artery long type which corresponds with short type ventral perineal artery were present in 12.5% of the studied cases (15% in males and 10% in females). When the ventral perineal artery is absent; that is the perineal trunk is present also runs together with the superficial perineal nerve, to vascularizes the skin, and the subcutaneous, and adipose tissue within the perineal region. It is interesting to note in this vascular variation the difference among gender from the 41% of the cases in which perineal trunk was present 24% were in males and 58% in females. In 76% (72 of the 95 pelvic halves with perineal trunk) the perineal trunk gives off two branches, one proximally and one distally, corresponding to the dorsal and ventral perineal arteries. However, in 24% (23 of the 95 pelvic halves with perineal trunk) the perineal trunk runs caudoventrally giving off small scattered branches along it course. In which 6 cases were in male and 17 in female pelvic halves.

Equal vascular pattern in either hemi-pelvises, that is symmetry between right and left sides, is an interesting issue concerning anatomical variations. It is worth noting that the specific percentages were especially low for the dorsal perineal artery long type vascular variation 0.4% and also for the presence of perineal trunk 5% as well as in the presumpted model 6% (Table 3).

Before excising a lesion in the perineal region, the regional blood supply should be assessed taking into account the possible arterial variations described herein. Perineal skin defects are often a challenge to reconstruct because little adjacent skin is available for local mobilization and elevation of subdermal plexus flaps large enough to cover extensive surface area.[18] Regional variation in cutaneous circulation of the perineum has been suggested, because subdermal flaps appear to be more susceptible to partial necrosis compared with similar flaps to other body regions.[29] The variability in the survival rate of flaps from the scrotum may be due to the variability of the vascular supply of the region as described by several authors.[13,30] In addition, the accidental ligation of vessels due to the presence of an aberrant vascular pattern may be the cause for necrosis of the flap, in fact the ligation of an aberrant, bilateral perforating branch of the cranial epigastric artery was reported to result in necrosis of 53% of the flap area.[8] AVBVS were also observed in the pudendoepigastric arterial trunk and vein when studied the cranial rectus abdominus muscle pedicle flap.[9] Regional blood supply must be investigated to improve consistency and viability of flaps when vulvar fold are used as transposition flap for perineal defects reconstruction.[14] Variations in surviving flap length may be secondary to variations in the number and location of branches of the direct cutaneous arteries, which influences total flap circulation and viability and distal necrosis was detected in 30% of the studied cases.[31] Adequate anatomical landmarks are necessary for consistent construction of large direct cutaneous arterial flaps.[32] AVBVS may determine the arterial displacement from a pedicle graft, in that case surgeon should consider orienting the flap pedicle in the direction of the direct cutaneous aberrant artery to help to assure an adequate perfusion pressure to the flap´s subdermal plexus. New flaps for surgery on the perineal region can be devised if the surgeon knows the origin and distribution of the perineal arteries.

It can be useful to identify perineal arteries and to consider possible AVBVS to prevent or minimize complications during perineal herniorrhaphy. Postoperative haemorrhage is associated with any surgical technique used to treat perineal fistula and herniorrhaphy.[19] In addition, severe haemorrhage can occur in dogs treated with cryosurgery[20] and it has been speculated that the perineal or caudal rectal arteries may be damaged by the freezing process and temporarily occluded.[20,21]

We suggest that knowledge of the location of arteries with respect to easily identifiable landmarks will help to avoid complications at surgery. Preoperative angiography may be necessary to determine blood supply and if is the case the presence of AVBVS. New surgical approaches to the perineal region may be devised if the surgeon knows the origin and distribution of the perineal arteries.

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DISCLOSURE

The authors declare no conflict of interest related to this report.

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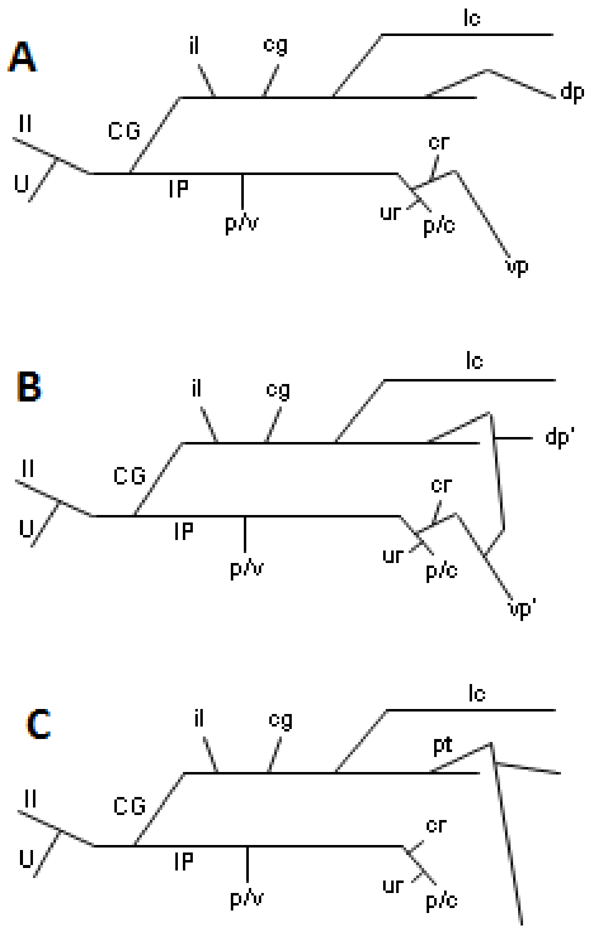

Fig. 1. Schematic representation which summarizes the anatomical variations of the perineal arteries. A) Presumptive anatomical model; B) Variation with dorsal perineal artery long type; C) Variation with perineal trunk. CG: caudal gluteal; cg: cranial gluteal; cr: caudal rectal; dp: dorsal perineal; dp´: long type dorsal perineal; II: internal iliac; il: iliolumbar; IP: internal pudendal; lc: lateral caudal; p/c: penis/clitoris; pt: perineal trunk; p/v: prostatic/vaginal; U: umbilical; ur: urethral; vp: ventral perineal; vp´: short type ventral perineal

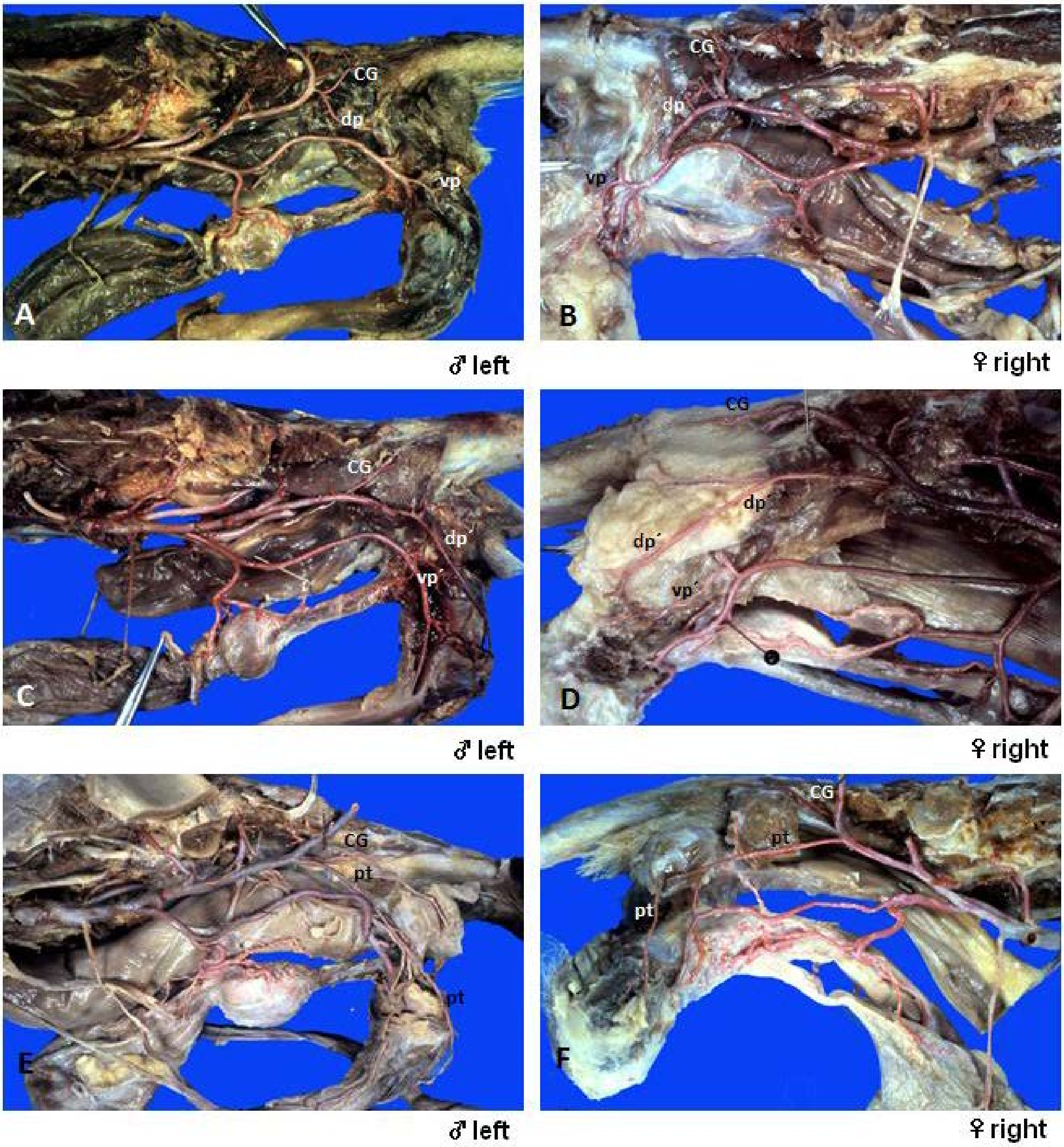

Fig. 2. Macrophotographs of 6 hemi-pelvises from male (left side) and female (right side) dogs, showing the final results of the anatomical preparations. A,B)Presumptive anatomical model; C,D) Variation with dorsal perineal artery long type; E,F) Variation with perineal trunk. CG: caudal gluteal; dp: dorsal perineal; dp´: long type dorsal perineal; pt: perineal trunk; vp: ventral perineal; vp´: short type ventral perineal.

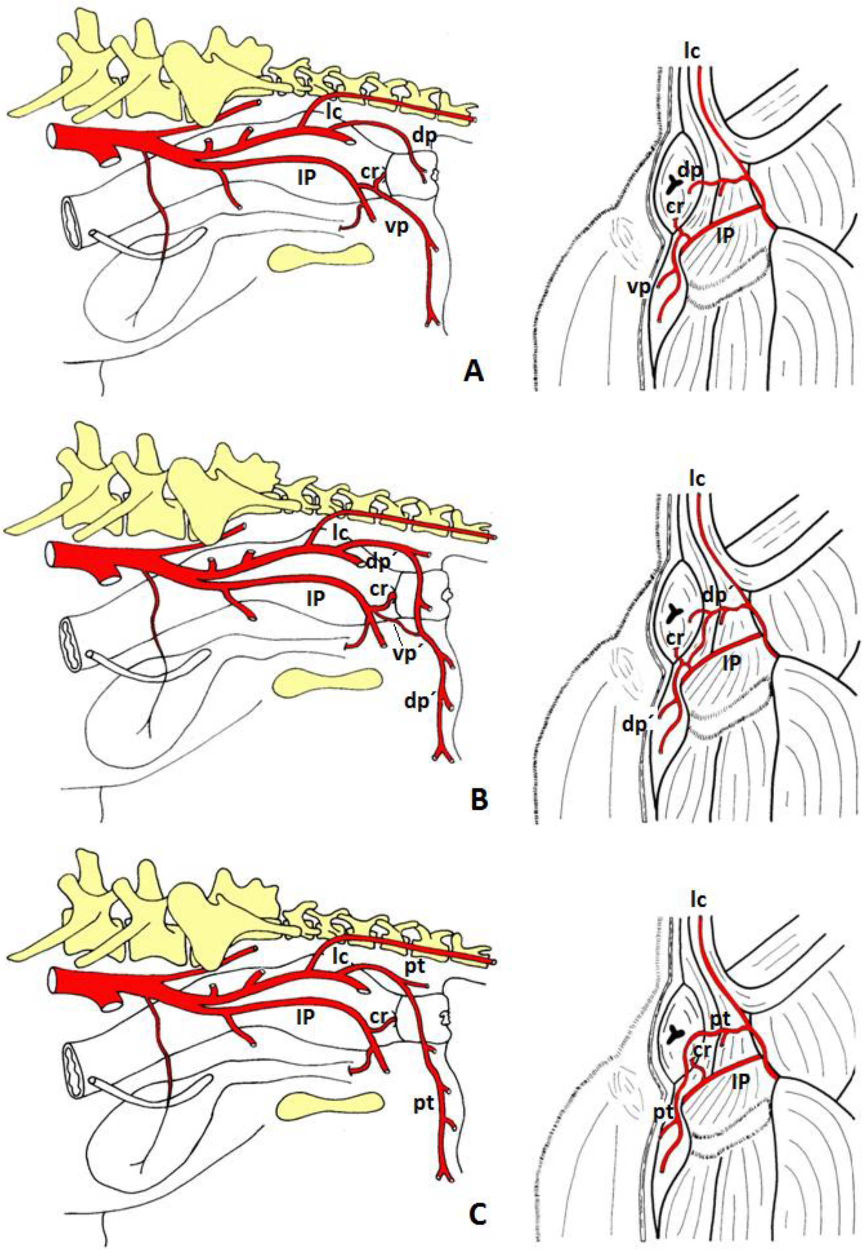

Fig. 3. Perineal arteries variation in relation to the presumptive model (A), dorsal perineal artery long type (B), perineal trunk (C). cr: caudal rectal; dp: dorsal perineal; dp´: long type dorsal perineal; IP: internal pudendal; lc: lateral caudal; pt: perineal trunk; vp: ventral perineal; vp´: short type ventral perineal.

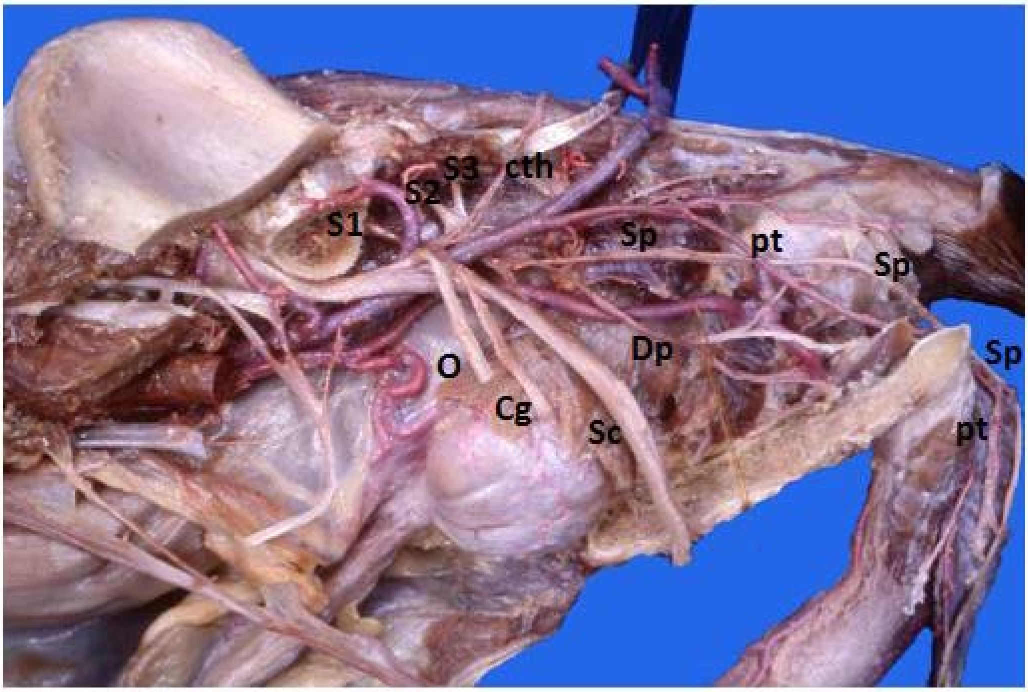

Fig. 4. Macrophotographs of hemi-pelvis from a male dog, showing the final results of the anatomical preparation in which the innervation is exposed, note the superficial perineal nerve constantly coursing together with the perineal trunk. cth: caudal nerves of the thigh; Cg: cranial gluteal nerve; Dp: deep perineal nerve; O:obturator nerve; pt: perineal trunk; Sc: sciatic nerve; Sp: superficial perineal nerve; S1: first sacral nerve; S2: second sacral nerve; S3: third sacral nerve.

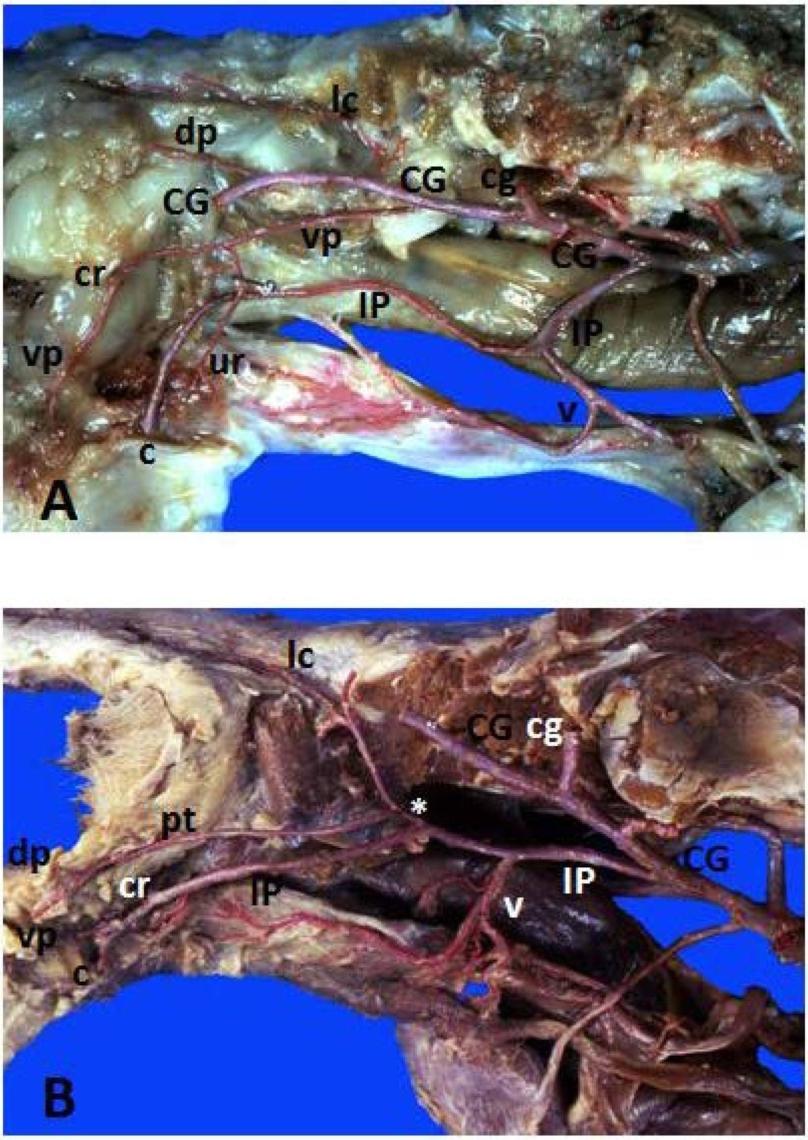

Fig. 5.Macrophotographs of 2 hemi-pelvises from 2 female dogs, showing the final results of the anatomical preparations. A) The vp artery arises from CG artery distally to the origin of the cg artery and gives off cr artery. B) IP gives off a common trunk (asterisk) for the lc artery and a perineal trunk that gives off dp and vp arteries. CG: caudal gluteal; cg: cranial gluteal; c: artery of the clitoris; cr: caudal rectal; dp: dorsal perineal; IP: internal pudendal; lc: lateral caudal; pt: perineal trunk; ur: urethral; v: vaginal; vp: ventral perineal.

TABLES

Table 1. Data for anatomical variations of the perineal arteries considering pelvic halves.

	Sex		Side		Profile			Size		
	Male	Female	Left	Right	Brach	Mesa	Dolich	Small	Med	Big
ATV	116	116	116	116	30	180	22	62	46	124
1.1	Traditional anatomical model. Number of cases: 106 = 45,70%									
n	71	35	54	52	14	88	4	36	19	51
%	61,21	30,16	46,54	44,83	46,67	48,89	18,20	58,05	41,30	41,13
1.2	Dorsal perineal artery “long type”. Number of cases: 29 = 12,50%									
n	17	12	18	11	4	22	3	3	6	20
%	14,65	10,33	15,52	9,47	13,34	12,23	13,64	4,84	13,00	16,13
1.3	Perineal trunk. Number of cases: 95 = 41%									
n	28	67	43	52	11	69	15	22	21	52
%	24,14	57,76	37,10	22,40	36,67	38,34	68,20	35,47	45,65	42,00

ATV, anatomical variation type; n, Number of cases; %, percentages in relation to the total specimens.

Table 2. Chi-squared data in relation to sex, side, profile and size; $P \leq 0.05$ significant

		Sex	Side	Profile	Size
Degrees of freedom	T number	1	1	2	2
1.1. Pearson chi-square	1.1	22.5121	0.0695	7.4626	5.2221
1.1 *P*-value	1.1	0.0000	0.7921	0.0240	0.0735
1.2. Pearson chi-square	1.2	0.9852	1.9310	0.0577	4.8327
1.2 *P*-value	1.2	0.3209	0.1646	0.9716	0.0892
1.3. Pearson chi-square	1.3	27.1127	1.4439	7.4843	1.2365
1.3 *P*-value	1.3	0.0000	0.2295	0.0237	0.5389

Table 3. Data for vascular symmetry pattern in bilateral hemi-pelvises with regard to each type of variation

	Traditional anatomical model		Dorsal perineal artery “long type”	Perineal trunk	
n	11	♂ / 4♀	1 ♂	3	♂ / 9♀
%	6,46		0,43	5,17	

n, Number of cases; %, percentages in relation to the total specimens.

5. DISCUSIÓN

Aunque en la normativa oficial no está explicitado como sería deseable se entiende que en la modalidad de tesis doctoral por “formato de publicaciones” son las propias publicaciones aportadas las que dan fe del trabajo realizado, en tanto que en ellas consta el contenido del mismo minuciosamente, que incluye lógicamente la preceptiva discusión. En ese sentido, es natural que surjan dudas sobre el enfoque más adecuado que deba seguirse para redactar este apartado de la memoria. Una opción consistiría en traducir al castellano, en su totalidad o en parte, la discusión elaborada para los artículos pero tal enfoque no es de extrañar que se considerase como simplista, y se descarta. En la modalidad en la que se incluye la memoria, otra alternativa, que a veces se utiliza, sería la de explicar minuciosamente la coherencia existente entre los manuscritos elaborados, pero en este caso se entiende como innecesaria ya que todos ellos abordan la misma temática. Por otro lado, en los apartados del capítulo 1 se ha intentado poner de relieve el estado actual del tema para lo cual se han abordado cuestiones de tipo general (apartado 1.1), una aproximación de lo que sucede en la especie humana (apartado 1.2) que es muy esclarecedora para de poner de manifiesto la situación en los mamíferos domésticos, asunto que se ha abordado con posterioridad (apartado 1.3). Ese capítulo demuestra que las VASVS están poco estudiadas en veterinaria y que en concreto las referidas a la AII son prácticamente inexistentes si se exceptúan las publicaciones ya comentadas de Gyürü y Kovács (1967) y Nitschke y Preuss (1971) ambas con un enfoque comparado de la citada arteria entre especies, y la de González y col. (2014) sobre las variaciones de las arterias braquiocefálica e ilíaca interna en el gato, trabajo que puede considerarse poco consistente para los conocedores de la anatomía veterinaria. Esta situación hace que sea harto difícil confeccionar una discusión entre resultados obtenidos e información previa que no pasase por repetir todo lo consignado con antelación, lo que tampoco se considera pertinente. Teniendo en cuenta las argumentaciones precedentes la redacción que se incluye a continuación se dedicará a resaltar los aspectos de mayor interés del estudio realizado, por lo que la presente discusión contemplará un conjunto de observaciones generales que conducirán a las conclusiones finales, tal y como constan en el epígrafe correspondiente.

De acuerdo con la bibliografía existente el estudio que se incluye como memoria de tesis doctoral es pionero en el campo de las VASVS ya que es la primera vez en el mundo que se abordan las consideraciones de VAs en un vaso concreto, como es la AII, con un enfoque predominantemente morfológico y refrendado por un número de casos tan elevado. Los 116 animales utilizados significan que se han examinado 232 muestras. Conviene señalar que un número indeterminado de animales se eliminaron del estudio por problemas en la preparación de las muestras, fundamentalmente aquellos debidos a una defectuosa repleción del sistema arterial analizado; los problemas surgieron no por fallos en la manipulación de los especímenes sino por las condiciones en que ciertos animales llegaban a la sala de disección. Ello quiere decir que el procedimiento de lavado/perfusión, repleción con látex coloreado y posterior fijación fue el idóneo en todas las muestras seleccionadas. En cuanto al procedimiento estadístico, el test de chi-cuadrado fue el recomendado por expertos en la materia para un estudio de estas características ya que, aunque es un test básico muestra un nivel de significación del 0.05.

El número de casos utilizado ha permitido evaluar las variaciones encontradas con respecto a tres factores objetivos como son el sexo, la simetría (derecho/izquierdo) y el perfil, y con otro factor cual es el tamaño de los animales, aunque lamentablemente no fue posible establecer una relación entre variaciones anatómicas y edad, como en principio se había programado. En cada uno de los manuscritos incorporados a la memoria se destacan las variaciones que son estadísticamente significativas.

Otro aspecto fundamental del trabajo, que en principio podría prestarse a cierta controversia, es el modelo elegido para establecer comparaciones. Sin embargo la elección de tal modelo no fue hecha de manera aleatoria sino que fue elaborado en base a las descripciones de los vasos contenidas en los libros de la especialidad, entre los que se incluye desde luego a la NAV. La bondad del modelo quedó corroborada con los resultados obtenidos ya que en todos los tipos de variaciones el patrón constituía la modalidad de distribución arterial porcentualmente más alta. En la figura 9, que recoge de manera sumaria las variaciones de la arteria glútea caudal y pudenda interna, se incluyen propuestas para representar convenientemente las VASVS correspondientes a los vasos indicados, siguiendo un criterio muy similar que el empleado para estos supuestos por los anatomistas humanos.

La complejidad en la formación del sistema vascular, recogida en los libros de texto de embriología humana (Tuchmann-Duplessis, 1970; Sadler, 2004; Rohen & Lütjen-Drecoll, 2008) y veterinaria (Zietzschmann & Krölling, 1955; Latshaw, 1987; Noden & deLahunta, 1990; Rüsse & Sinowatz, 1991; McGeady et al., 2006; Hyttel et al., 2009; Salazar, 2013), debe considerarse como la causa más frecuente en la presentación de VASVS, sin que en ningún caso ese tipo de variaciones constituyan malformaciones. Es evidente que la citada complejidad en la formación de los vasos va asociada a la propia complejidad del recorrido y ramificaciones que una arteria tenga en el individuo adulto. Por otra parte, la funcionalidad de tal o cual vaso, o lo que es lo mismo, el territorio al cual está destinado, justificaría la presencia de un tipo u otro de variación. En principio debería suponerse que existiría una mayor predisposición a la presentación de variaciones en las arterias viscerales que en las parietales. Como se mencionaba en párrafos anteriores hay posibilidades de establecer correlaciones significativas entre tipos de variaciones de la AII con respecto al sexo, lado derecho o izquierdo, perfil y tamaño de los animales.

El conocimiento de la existencia de VASVS tiene un indudable valor intrínseco anatómico pero también profesional y clínico o médico como se pone de manifiesto en medicina humana.

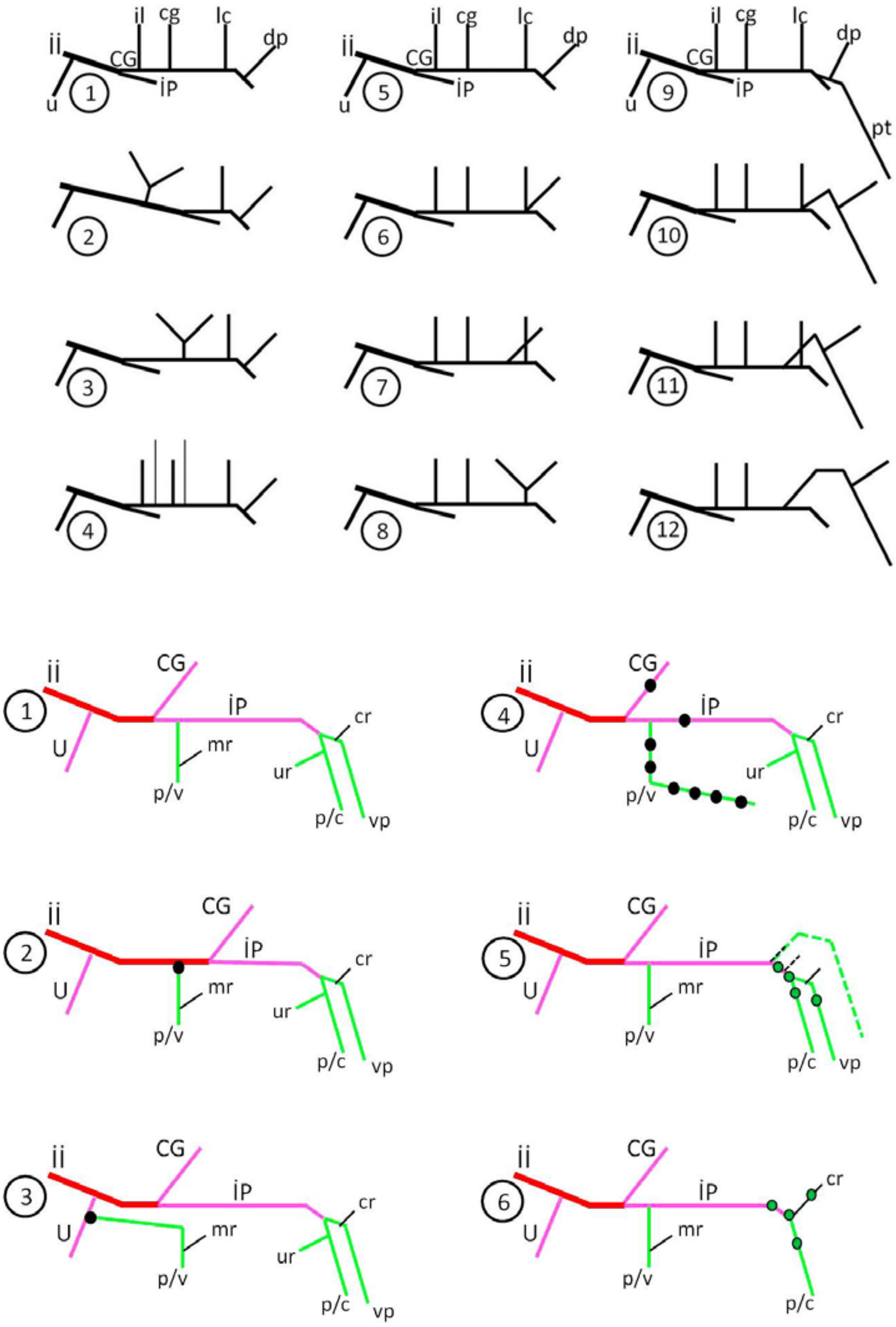

Figura 9. Reproducción de los esquemas originales que ilustran las variaciones anatómicas de la arteria glútea caudal (superior) y pudenda interna (inferior) en el perro con respecto al modelo seleccionado (1). II, ilíaca interna; CG, glútea caudal; IP, pudenda interna; U, umbilical; cg, glútea craneal; cr, caudal rectal; dp, perineal dorsal; il, iliolumbar; lc, caudal lateral; p/c, pene/clítoris; pt, tronco perineal; p/v, prostática/vaginal; ur, uretral; vp, perineal ventral. Según Avedillo et al., 2014; 2015.

5. CONCLUSIONES

Las variaciones anatómicas que presenta el perro adulto referidas a la arteria ilíaca interna son numerosas y heterogéneas. En un porcentaje superior a cinco, se ha observado que la propia arteria ilíaca interna muestra una variación anatómica descrita como de tipo largo, lo que lleva consigo un desplazamiento caudal en el origen tanto de la arteria glútea caudal como de la arteria pudenda interna. Como consecuencia de esta variación, las arterias iliolumbar y glútea craneal tienen un tronco común que parte de la arteria ilíaca interna.

Adicionalmente a lo consignado en el párrafo anterior para la arteria glútea caudal ésta presenta siete variaciones anatómicas repetitivas de las que tres se refieren al origen, disposición y relación de la arteria perineal dorsal con la arteria caudal lateral. Las cuatro variaciones restantes son consecuencia de la aparición de un vaso adicional, que se ha denominado tronco perineal, que tiene un origen cambiante.

Adicionalmente a lo consignado en el primer párrafo para la arteria pudenda interna ésta presenta catorce variaciones anatómicas repetitivas todas ellas referidas al origen de sus ramas: dos tipos de variaciones que afectan a la arteria prostática/vaginal, seis tipos de variaciones que corresponden a la arteria rectal media, tres tipos de variaciones que conciernen a la arteria uretral y otros tres tipos de variaciones que se relacionan con la arteria perineal ventral y rectal caudal.

Con respecto a la arteria umbilical prácticamente no se detectaron variaciones anatómicas relevantes en cuanto a su origen ya que en doscientas veintiséis de las muestras estudiadas era constante, a la altura de la séptima vértebra lumbar, por lo que las seis modificaciones encontradas pueden considerarse como accidentales. En cuanto a sus ramas, únicamente se observó que la arteria prostática, un caso, y la arteria vaginal, seis casos, tenían su origen en la arteria umbilical. Por el contrario, en ciento seis medias pelvis se constató que la arteria umbilical daba lugar a la arteria vesical craneal, lo que significa que la mencionada arteria es permeable en un porcentaje superior al cuarenta y cinco.

A excepción de lo que sucede con el origen de la arteria rectal media que es extraordinariamente cambiante, en el resto de los vasos su origen se corresponde con el modelo seleccionado en porcentaje superior al treinta por ciento.

Dependiendo de la arteria considerada, las variaciones anatómicas observadas son comunes a los lados derecho e izquierdo en un tanto por ciento elevado de los casos en el origen de la arteria rectal media y en la existencia de la arteria vesical craneal.

6. BIBLIOGRAFÍA

Las referencias bibliográficas que se incluyen en este apartado corresponden a las que se aluden en los capítulos de Introducción y Discusión más todas aquellas que constan en las publicaciones y manuscritos aportados. A pesar de que finalmente esta relación puede consisderarse extensa no es ni mucho menos exhasutiva ya que son muchos los artículos que no han sido incluidos, especialmente los relacionados con la especie humana.

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